State of California
The California Natural Resources Agency
Department of Water Resources
FloodSAFE Environmental Stewardship and Statewide Resources Office

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Technologies for Passing Fish at Large Dams

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Technologies for Passing Fish at Large Dams

Introduction

Background

In 2006, California voters passed Proposition 84, The Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act. The Act directed the California Department of Water Resources (DWR) to conduct planning and feasibility studies to improve the integration of flood control and water supply systems. In 2008, the Governor signed into law Senate Bill X2 1 which appropriated funds to DWR for planning and feasibility studies to identify potential options for the reoperation of the state's flood protection and water supply system. Senate Bill X2 1 reinforced the importance of water to the State of California and focused on the need for proactive and innovative water management in the face of climate change, an increasing population, and the realization that the status quo will not meet future water needs. The bill requires DWR to evaluate ways to integrate and reoperate flood protection and water systems under various potential climate change scenarios and provide four benefits:

- increase water supply reliability
- increase water use efficiency and water conservation measures
- reduce energy consumption associated with water transport
- protect and restore ecosystems and wildlife habitat

Recent documents have reinforced the need for an evaluation of the potential to reoperate the State's water management and flood protection systems. The California Water Plan Update 2009 recommended the state manage its water resources with ecosystem health and water supply reliability and quality as equal goals, and stated that reoperation of the water management systems can provide benefits in a changing climate. In the Central Valley salmonid recovery plan, the National Marine Fisheries Service (NMFS) recommended that the State develop alternative water operations and conveyance systems that improve conditions for Central Valley salmonids and that restore the ecological flow characteristics of the Delta ecosystem (NMFS 2009a). Additionally, NMFS (2009a) recommended that water and salmonid management be integrated, in consideration of variable ocean conditions and climate change.

Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water, California Water Plan Update 2009, and 2009 CA Climate Adaptation Strategy call for the establishment of

> "…a System Reoperation Task Force composed of State personnel, federal agency, and Tribal representatives, and regional and local governments, agencies, and organizations to:
>
> - quantify the potential costs, benefits and impacts of system reoperation for water

supply reliability, flood management, conjunctive water management, hydropower, water quality, fish passage, cold-water management for fisheries, and other ecosystem needs;

- support the update of US Army Corps of Engineers operations guidelines (“rule curves”) for Central Valley reservoirs;
- support the update of flood frequency analyses on all major rivers and streams;
- evaluate the need to amend flow objectives;
- expand the study of forecast-based operations for incorporation into reservoir operations guidelines;
- include watershed level analyses that detail localized costs and benefits;
- identify key institutional obstacles that limit system reoperation benefits;
- communicate and promote demonstration project results to encourage broader participation in system reoperation analyses; and
- identify dam safety issues.”

Implications of Climate Change

California’s water resources infrastructure does not meet existing, often competing objectives for water supply, flood protection, environmental protection, water quality, hydropower and recreation. Fish populations are at all time lows, and decisions about water diversions are being decided in the courts. In 2008, the Governor’s Delta Vision task force stated that California’s water supply is limited and must be managed with significantly higher efficiency to be adequate for its future population, growing economy, and vital environment. The goals of conservation, efficiency, and sustainable use must drive California water policies (Blue Ribbon Task Force 2008.)

In order to make water supply and flood management systems more sustainable, those systems should preserve, enhance and restore ecosystem functions (DWR 2008). Climate change will bring an additional level of variability to our water system. Current climate change models predict a range of impacts that should be considered in water system reoperation. A few that are particularly important for salmonid species include:

- sea level rise which leads to increased salinities in the Delta
- more frequent intense winter storms, resulting in high stream flow events and floods
- more precipitation as rainfall with less snowpack and earlier snowmelt, higher peak flows in winter, less spring runoff, and much lower summer flows, and
- considerably warmer stream, river, and ocean water temperatures during the summer

Lindley and others’ (2007) work examining the effects of climate warming on the availability of over-summer habitat for spring-run Chinook salmon illustrates the implications of how climate change could affect Central Valley salmon. Spring-run Chinook salmon migrate upstream from the ocean in spring, hold through the summer in deep pools, and then spawn in early fall. Analysis by Lindley et al. (2007) suggests that a 2°C increase in water temperatures might eliminate summer holding habitat for Butte Creek, where one of three viable populations of spring-run Chinook salmon in the Central Valley remain.

Decreases in Sierra Nevada snowpack also have negative implications for Chinook salmon. The Central Valley’s largest surface reservoir is the Sierra Nevada snowpack. That snowpack melts slowly in the spring and summer. There are 395 reservoirs with a capacity of at least 50 acre-feet that are fed by the Sierra Nevada. Their combined storage capacity is approximately 14 million acre-feet. The Sierra Nevada snowmelt provides an annual average 15 million acre-feet of water to those reservoirs. DWR (2008) projects a 25 to 40 percent reduction in the Sierra snowpack because of warmer storms resulting in less snowfall. This could result in higher flows earlier in the year, and lower flows in the summer when spring-run Chinook salmon would be holding in deep pools that are smaller and/or fewer.

System Reoperation and Fish Passage

Given the possible conditions that may exist in Central Valley streams as the climate warms, many researchers and agencies have recognized the need to evaluate opportunities to provide Central Valley salmonid species access to currently inaccessible habitat (DWR 2008, NMFS 2009, and CA Resources Agency 2009). In addition, Lindley et al. (2007) stated that in order to recover Central Valley salmonids, some populations will need to be established in areas now blocked by dams.

> "The state should work with dam owners and operators, federal resource management agencies, and other stakeholders to evaluate opportunities to introduce or reintroduce anadromous fish to upper watersheds. Reestablishing anadromous fish, such as salmon, upstream of dams may provide flexibility in providing cold water conditions downstream, and thereby help inform system reoperation." (CA Resources Agency 2009)

The U.S. Bureau of Reclamation dedicates over 1.2 million acre-feet of water, through operation of the Central Valley Project, to fish and wildlife. DWR releases water to meet minimum flow and temperature requirements downstream of Oroville Dam. Climate change may warm rivers and streams, with less water available for ecosystem flow and temperature needs in spring and summer (CA Resources Agency 2009). As temperatures warm, more cold water storage may be needed so that releases can be made to meet temperature requirements downstream. Providing anadromous[1] fish passage to areas upstream of reservoirs could eliminate or reduce the need for cold water releases and give water managers additional flexibility in meeting downstream water supply and flood protection needs.

In addition, it is prudent to consider fish passage opportunities as part of potential systems reoperations because other agencies are conducting planning efforts for fish passage in the Sacramento (Keswick and Shasta dams), American (Nimbus and Folsom dams), and Stanislaus (Goodwin, Tulloch, and New Melones dams) river watersheds (NMFS 2009b). NMFS, DWR, and others are also evaluating fish passage at Englebright Dam on the Yuba River as a step in the Habitat Expansion Agreement process for the FERC Relicensing of Oroville Dam (DWR 2007). Finally, NMFS has recommended that the state and its partners also evaluate opportunities for fish passage on the San Joaquin (Friant Dam), Merced (Crocker-Huffman and New Exchequer dams), Mokelumne (Camanche and Pardee dams), Calaveras (New Hogan Dam), Feather River (Oroville Dam), Stony Creek (Black

[1] Anadromous fish, such as salmonids, spawn in freshwater, migrate to the ocean to mature, and then return to freshwater to spawn and complete their life cycle.

Butte Dam), and Clear Creek (Whiskeytown Dam) as part of the suite of actions that must be taken to return winter-run Chinook salmon, spring-run Chinook salmon, and steelhead to viable status in the Central Valley (NMFS 2009).

Methods

In preparing this report, a literature search for information on upstream and downstream fish passage technologies at dams was conducted. The goal of the literature search was to acquire publications and other materials that described the technologies and their effectiveness at passing fish at dams greater than 68 feet. The highest known fish ladder in California that passed fish (at least periodically) is at San Clemente Dam, which has a hydraulic height of 68 feet. It was assumed that if the System Reoperation Studies looked at passing fish at dams at 68 feet or less, a ladder could be considered. Therefore “large dam” was defined as greater than 68 feet and information was provided on how upstream and downstream fish passage could be accomplished at structures greater than that height. The literature search was not limited to information for any one particular species.

We used several sources of information:

- Gray literature (like city, county, state and federal government publications)
- Peer-reviewed journals
- Internet
- Electronic databases and
- Books, newspapers, and magazines

From the literature search, gray literature and journal articles published through June 2010 using the internet and “Google” search engine and the UC Davis Library online catalog and databases were found. In addition, 17 online libraries and 10 online databases were searched using 22 keywords and their combinations (Appendix B). Further, experts in the field, facility operators within and outside the United States, and authors of technical articles were consulted.

Another key source of information was the National Inventory of Dams (U.S. Army Corps of Engineers) which includes a dataset of approximately 79,000 dams which meet at least one of the following criteria:

High hazard classification - loss of one human life is likely if the dam fails,
Significant hazard classification - possible loss of human life and likely significant property or environmental destruction,
Equal or exceed 25 feet in height and exceed 15 acre-feet in storage,
Equal or exceed 50 acre-feet storage and exceed 6 feet in height (U.S. Dept. of Interior 2011).

The literature search, National Inventory of Dams, and expert information yielded a list of 120 large dams (i.e. greater than 68 feet) from around the world that use various techniques to provide fish passage (Table 1). We reviewed over 450 references and over 1,000 websites to gather additional information used in the report (Appendix C).

Report Layout

The report is divided into four sections: **Problems with Dams**, **Fish Passage Technologies**, **Fish Passage Case Studies**, and **Conclusions**.

The first section, **Problems with Dams**, gives the reader a basic understanding of the problems that dams create for migratory fish, especially salmon and steelhead. By understanding the ecological problems that dams create for salmon and steelhead, the reader can better evaluate the benefits that fish passage to upstream areas can provide.

The second section, **Fish Passage Technologies**, provides a general overview of fish passage technologies. We define fish passage technologies as methods or devices used to pass fish and water around, through, or over an obstruction so that the fish can move upstream or downstream with minimal stress (Clay 1995). The section contains a description of each method or device including images that will help the reader visualize how each technology works.

The third section, **Fish Passage Case Studies**, describes specific examples of fish passage technologies being used around the world. Each case study includes a description of the dam or dams and associated facilities, the history of fish passage at the dam(s), fish passage technology currently in use or in development, unique problems or issues, costs, and any evaluations of the technology's effectiveness. The level of detail among the case studies varies. We provide as much detail as was available at the time this report was written.

The fourth section, **Conclusions**, provides the basis for the need to examine of fish passage in California and summarizes the case studies.

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Problems with Dams

Large Dams Defined

Large dams may be defined various ways for different purposes and objectives. Dams vary tremendously in size (height and width) and hence in their reservoir storage volume, factors that have very important direct and indirect environmental impacts (Poff 2002).

Worldwide, there are greater than 45,000 dams above 15 m high (49 ft), capable of holding back more than 6500 km^3 of water, or about 15% of the total annual river runoff. Over 300 dams are defined as giant dams, which meet one of three criteria: height greater than 150 m (492 ft), dam volume greater than 15 million m^3 (19.6 million yd^3), or reservoir storage greater than 25 km^3 (20.25 million acre-feet). The recently constructed Three Gorges Dam on the Chang Jiang (Yangtze) River in China is an example of a giant dam, 181 m (593 ft) high, storing more than 39 km^3 (31.5 million acre-feet) (Nilsson 2005).

In this report, the term “large dam” is defined as having a height greater than 68 ft. Other organizations, like the International Committee on Large Dams and DWR’s Division of Safety of Dams, use different criteria to define a “large dam” or to determine whether a dam falls within their purview.

As noted by Poff (2002), there are at least two reasons why criteria are problematic for defining dam characteristics from the perspective of environmental effects. First, the same dam can be classified as large according to one definition and not large according to another. Second, even if only one definition is adopted, dams that are grouped together can vary tremendously in size. For example, the U.S. Army Corps of Engineers’ National Inventory of Dams database of dams includes structures with heights ranging from less than 2 m to more than 200 m, and storage volumes from less than 100 m^3 (0.8 acre-feet) to 37 billion m^3 (30 million acre-feet). Such marked differences in dam size will necessarily translate into very different uses and environmental effects. It is important to note that height does not always share a direct relationship with factors like environmental impacts, displacement, total storage volume, or submergence area (Shah 2009).

Large dams may be labeled as “reservoir storage type projects” or “run-of-river dams.” Reservoir projects impound water behind the dam for seasonal, annual, and, in some cases, multi-annual storage and regulation of the river. In addition, these dams generally provide flood control and hydropower generation (Word Commission on Dams 2000). Run-of-river dams create a hydraulic head in the river to divert some portion of the river flows to a canal or power station. Water flowing out of the power station is then redirected back to the natural flow of the river (Word Commission on Dams 2000). Run-of-river dams typically are built on a river with consistent steady flow, do not require a large reservoir (have storage for less than 48 hours of water supply), and tend to be on a smaller scale (CleanTech 2008). Within these general classifications there is considerable diversity in scale, design, operation, and potential for adverse impacts.

Dams in California

California’s vast statewide water management system includes a network of hundreds of groundwater basins, over 1,400 state, federal, and local dams, and thousands of miles of canals, aqueducts, and levees which deliver water and manage floods for more than 38 million people (Hanak 2011). These systems are often interconnected, with one system relying on the successful operation of another (DWR 2009). Water from California’s dams is routed through surface delivery systems for many beneficial uses, including: municipal, domestic, industrial, and agricultural supply; stockwatering; aquaculture; frost protection; heat control; mining; groundwater recharge; water quality; water recreation; navigation; and flood management. Hydropower generation, which represents about 20% of the electricity used within the state, takes place on all major river systems within California (PIER 2005). In addition, water stored in reservoirs is also used to protect special status species, preserve and enhance fish and wildlife habitat, and provide attraction flows for migrating fish.

Historically in California, the large reservoirs, such as Shasta or Folsom, were not provided with up or downstream fish passage. Instead, hatcheries were constructed for salmonid species to compensate for lost spawning and rearing habitat (PIER 2005). Because many California salmon runs are listed as endangered or threatened, the provision of fish passage at many of these large dams is being evaluated. Nationally, Francfort (1994) found, in an investigation of 1,825 Federal Energy Regulatory Commission (FERC) regulated hydroelectric dam sites, that upstream fish passage technologies were used at 9.5 % of the sites and downstream fish passage technologies were used at 13.0% of the sites.

USACE’s National Inventory of Dams database identifies over 1,400 dams within California (Figure 1), of which 370 are 68 feet or higher. Table 1 highlights large California dams that have been identified as needing fish passage by NMFS in the 2009 Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project, as well as, the Public Draft Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead (NMFS 2009a and b). NMFS (2009a) also calls for fish passage at many of the smaller California dams (i.e. less than 68 ft), but because this paper focuses on providing fish passage at large dams, we are highlighting the larger dams identified by NMFS.

Table 1. Key Dams in California Needing Fish Passage (NOAA Fisheries 2009a and b) (Streams listed from north to south; Dams are listed from downstream to upstream)

River	Dam	Year Dam was Built	Species	Struct. Height (feet)	Hydraulic Height (feet)	Crest Elev. (feet)	Storage (acre-feet)	Miles Blocked
Sacramento River	Keswick	1949	Current Limit of Anadromy on Sacramento River. Steelhead, spring-run and winter-run. Fall-run don't go much higher than 1000' in elevation.	157	118	595.5	23,800	13 + 52 including Shasta
Sacramento River	Shasta	1945	Steelhead, spring-run and winter-run. Fall run don't go much higher than 1000' in elevation.	602	522.5	1,077.5	4,552,000	52 for Sac River, Not including all of the tribs that feed Shasta
Clear Creek	Whiskeytown	1963	Fall-run, spring-run	282	252	1,228		9
Stony Creek	Black Butte	1989	Spring-run and fall-run	140	135			51
Feather River	Oroville	1968	Steelhead and fall and spring-run	770	721	922	3,537,577	147
Yuba River , North Fork	New Bullards Bar	1970		635	627		996,103	
Yuba River, Middle Fork	Our House	1968		70	66			
Yuba River, Main Stem	Englebright	1941	Spring-run, fall-run, and steelhead	280	260		45,000	~56 total
Yuba River, Oregon Creek	Log Cabin	1969		53	43			
American	Nimbus	1955	Steelhead and fall-run, spring-run, Possible late-fall run.	87	46	132	8,760	133 Total
American	Folsom	1955	Steelhead and fall-run, spring-run, Possible late-	340	275.4	480	1,010,000	

			fall run.					
Putah Creek	Monticello	1957		304	254.5	456	1,602,000	~8-15
San Joaquin River	Friant	1942	Spring-run, fall-run, and late-fall run	319	293	581.25	520,500	121
Mokelumne River	Camanche	1964	Fall-run, spring-run, Possible late-fall run, steelhead,	171		263	417,120	23
Mokelumne River	Pardee	1929		351.5				
Calaveras River	New Hogan	1963	Steelhead	210	195		317,000	
Stanislaus River	Goodwin	1912	Steelhead	101	81.1	379	500	67
Stanislaus River	Tullock	1915	Steelhead	205	200			
Stanislaus River	New Melones	1979	Steelhead	637	614	~750	2,420,000	
Tuolumne River	La Grange	1894		131	131	296.5	500	52
Tuolumne River	Don Pedro	1971		568	543	855		
Merced River	McSwain	1966		97	72			56
Merced River	New Exchequer	1966		479	464			

Note that Table 1 only includes available information. Therefore, some cells are blank.

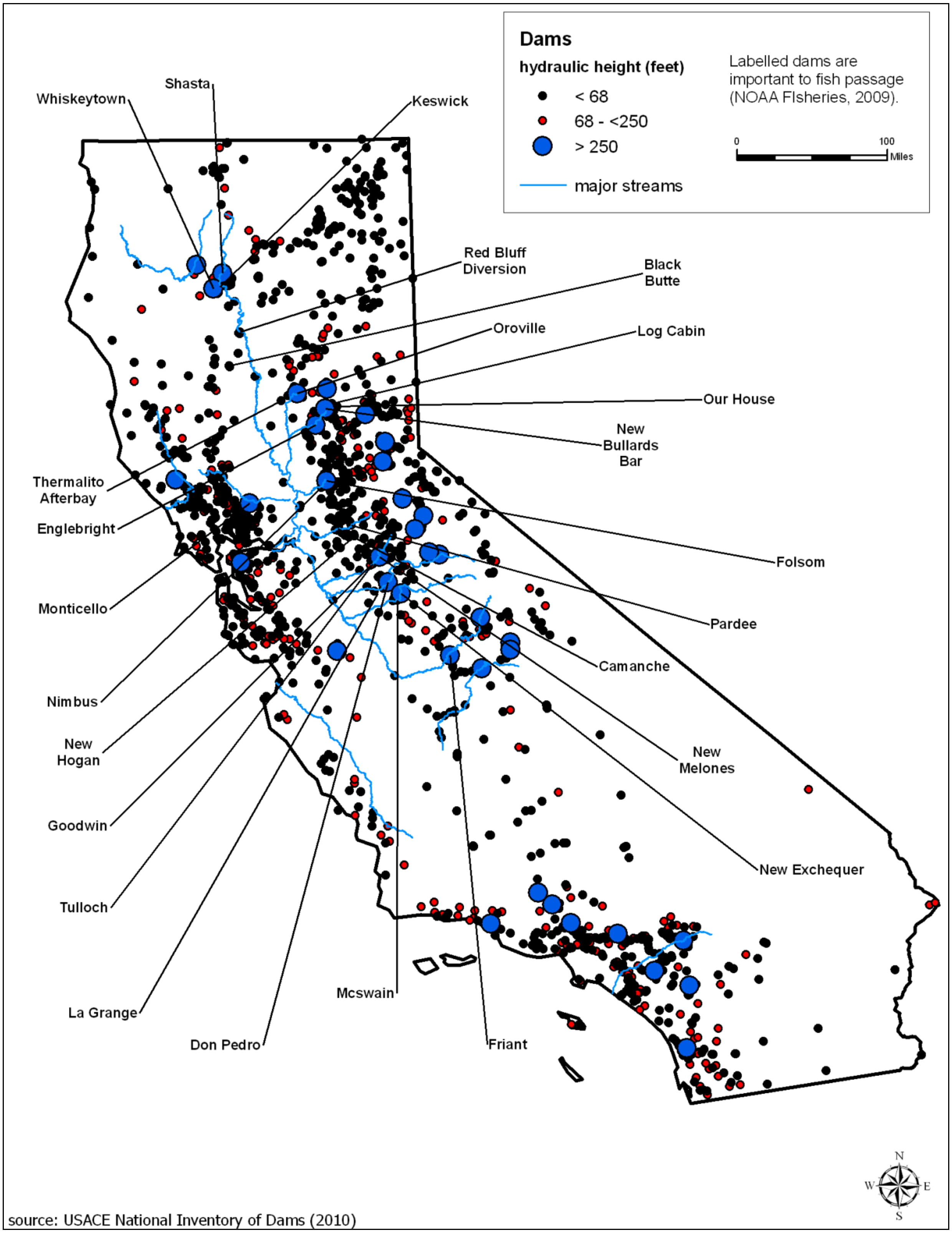

Figure 1. Dams in California (USACE NID 2010)

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Environmental Issues Associated with Dams

Impacts to riverine ecosystems caused by large dams have been well documented. Dams block or delay fish migration and access to habitat, and alter physical, chemical, and biological characteristics of rivers. This section provides an overview of the effects which existing dams have on fish and other aquatic life.

Blockage of Fish Migrations at Dams

The movements of aquatic organisms can be limited by dams which fragment and regulate rivers, and this can subsequently contribute to the population decline of special status fish species. A study by Nilsson et. al. (2005) found that over half (172 out of 292) of the world's large river systems are affected[2] by dams. Passage obstructions have been the reason for the extinction of entire stocks (salmon in the Rhine, Seine and Garonne Rivers) or for the confinement of certain species to a very restricted part of the river basin (salmon in the Loire River, shad in the Garonne and Rhône rivers) (Larinier 2000). Sturgeon stocks have been particularly threatened by hydroelectric dams on the Volga, Don, and Caucasian rivers (Larinier 2000). In France, there has been a continuous and increasing decline in stocks of migrating fish species: in a large majority of cases, the main causes of decline have been the construction of dams preventing free upstream migration (Larinier 2000).

In the U.S., declines of anadromous fish have occurred on both the East and West coasts. On the East Coast, the building of dams has been identified as the main reason for the extinction or the depletion of migrating species such as salmon and shad on the Connecticut, Merrimack and Penobscott Rivers (Larinier 2000). In the Pacific Northwest, many efforts have attempted to quantify the extent of the wild salmon decline. Nehlsen et al. (1991) concluded that over 200 salmon stocks[3] in California,, Oregon, Idaho, and Washington were at moderate or high risk of extinction. An assessment of British Columbia and Yukon stocks identified over 702 stocks at moderate or high risk. Across the Pacific Northwest, at least 100-200 stocks are already identified as extinct, but the actual number may be much higher (Lackey 2003). NMFS (1997) states that large hydroelectric projects in the Pacific Northwest have contributed to the population decline of these salmon stocks.

[2] Impact classification was based on river channel fragmentation and water flow regulation by dams.

[3] The Washington Department of Fish and Wildlife (2012) defines a stock as a group of fish that return to spawn in a given area at the same time and that are, for the most part, reproductively isolated from other such groups. A stock may include several local spawning populations. A **'run'** of fish may include more than one stock returning at the same time but destined for different spawning grounds .

In California's Sacramento-San Joaquin River system, large dams have blocked Chinook salmon access to over half of the stream reaches they once used and to over 80 percent of their historical holding and spawning habitat (Moyle 2002). The construction of large dams and diversions on all major rivers in California has been cited as a major cause in the decline of Chinook salmon in the State, as well as, the southern distinct population segment of North American green sturgeon and Central Valley steelhead populations (Moyle 2002, NOAA Fisheries 2005). Additional information on the decline of California anadromous fish is included in Section --- of this report.

Delay in Fish Migrations at Dams with Passage Facilities

Instream structures can be total, partial, or temporal barriers, or a combination of these. Large dams are often thought of as total barriers to migration, as discussed in the above section. Taylor and Love (2003) defines a total barrier as impassable to all fish at all flows. Fish may also encounter partial and temporal barriers while migrating through passage facilities. These are defined as:

Anadromous fish populations may be impacted by migration delays at large dams, even if a fish passage facility is present. Temporary barriers can adversely affect fish by delaying them during migration, causing them to stay in unsuitable downstream areas, or causing injury as a result of

Table 2: Definitions of barrier types and their potential impacts (DFG 2009)

Barrier Category	Definition	Potential Impacts
Temporal	Impassable to all fish at certain flow conditions (based on run timing and flow conditions).	Delay in movement beyond the barrier for some period of time.
Partial	Impassable to some fish species, during part or all life stages at all flows.	Exclusion of certain species during their life stages from portions of a watershed.
Total	Impassable to all fish at all flows.	Exclusion of all species from portions of a watershed.

repeated, fruitless attempts to pass over the dam (Larinier 2000).

Although the height of a barrier is often what blocks migration, even low weirs may become a barrier to fish passage under certain hydraulic conditions. The conditions that can adversely affect passage include high velocity, excessive water drop, shallow water depth, aeration, and turbulence. The relationship of these factors to a fish's swimming and leaping ability will determine whether passage is possible. Swimming and leaping ability depend on the species, the size and physiological condition of the individuals, and water quality factors such as water temperature and dissolved oxygen (Larinier 2000).

Changes in flow directly impact the effectiveness of fish passage facilities. During low flow conditions, a barrier may be insurmountable because the depth of water over the structure is too shallow to permit fish to swim or the drop is too high. The structure may however become passable at higher flows, as water depth increases and the drop at the structure decreases (Larinier 2000).

Barriers can delay the upstream migration of adult salmon migrating upstream and cause fish to move back downstream. The delay and fallback can result in mortality to adult salmon. One example of passage delay is when fish can't find the entrance to the fishway. Prior to the implementation of fish passage improvements at Red Bluff Diversion Dam, adult Chinook salmon were known to be delayed an average of three weeks due to the salmon's inability to readily locate the ladders at flows greater than 6,000 cfs (Bureau). Fallback can result in direct or immediate mortality because fish pass back downstream, either over the spillway or through mechanical structures (e.g. juvenile bypass or dam turbines). Wagner and Hilsen (1992) reported that injury rates of fall Chinook salmon that passed back downstream at McNary Dam were highest for larger fish, with bruises being the most common injury. This study also documented fallback through the turbines, a route that is known to kill adult salmonids (Dauble 1993).

Additional effects of delays include: exposing fish to intensive predation, to nitrogen supersaturation, and to disease organisms and parasites. Delays can also result in a significant portion of the juvenile population spending more time (e.g. several months) in fresh water instead of continuing at their normal rate of downstream migration to the ocean (Larinier 2000).

Creation of Lacustrine and Predator Habitat

Many ecological changes occur when a river is impounded by a dam. Terrestrial ecosystems, as well as riparian and fluvial habitats, are replaced by a lacustrine (lake) habitat. Open water circulations replace flow patterns that were previously confined to a river channel. These may be good for some species (e.g. water fowl and fish which spawn in open water) and in some areas (e.g., in a dry desert areas where a reservoir may be beneficial to terrestrial as well as aquatic biota, because it constitutes a permanent water resource). However, because a river and its tributaries represent a more varied habitat than a large lake, there is usually a decline in the total number of species (McCartney 2000).

The presence of a dam may create habitat which is more favorable to certain predatory species (Larinier 2000). The slower water flow and larger surface area created by dams can alter the species composition of organisms in the river, favoring slower-moving aquatic species that are better adapted to lake-like bodies of water. For example, along the dammed Snake River in the Pacific Northwest, slow-moving, reservoir habitat has led to an increase in fish species that prey on salmon and steelhead populations, exacerbating the continual decline of these populations along the Snake River.

In addition to changes in species composition, dams may also affect the distribution of predatory fish in the reservoir. Increased predation on migratory fishes has been indirectly linked to hydropower dams (OTA 1995). Migrating species suffer increased predation near hydropower facilities, whether by other fish or birds. This may be due to the unnatural concentration of fish upstream of the dam in the forebay, or to fish becoming trapped in turbulence or recirculating eddies downstream of spillways, or to shocked, stressed and disoriented fish being more vulnerable to predators after turbine passage. Fish which are delayed (as discussed above) may also be more susceptible to predation. (Larinier 2000)

Hindrance of Sediment Transport

Changes in sediment transport have been identified as one of the most important environmental impacts of dams. As soon as a dam is operational, it will begin to trap sediment. How quickly this occurs depends on watershed size, topography and geology, as well as the initial reservoir capacity, inflow characteristics and reservoir management (McCartney 2000). However, the process of sedimentation is essentially the same for all reservoirs. As the relatively high velocity and turbulent water of rivers draining into the reservoir are slowed within it, the sediment load is deposited. Sediment is deposited both in the reservoir and, as a result of backwater effects, in the channel and valley bottom upstream (McCartney 2000).

Many reservoirs store almost the entire sediment load (typically 90%) supplied by the drainage basin. It is estimated that around 50 cubic km of sediment are trapped behind the world's dams every year (McCartney 2000). McCartney (2000) estimated that in total, about 1,100 cubic km of sediment has accumulated in the world's reservoirs. There are numerous studies that report sediment storage behind dams. For example, Kummu (2007) calculated the theoretical trapping efficiency (TE) for four dams on the Mekong River in China. The theoretical TE for Manwan Dam, completed in 1993, was 68%, which correlates with the measured TE of 75%. The Dachaoshan Dam, completed in 2003, has a theoretical TE of 66%, while the bigger dams Xiaowan, constructed between 2002 and 2010, and Nuozhadu, presently under construction, were predicted to have theoretical TEs as high as 92%, basically trapping all the sediment.

In the U.S., the Glen Canyon Dam on the Colorado River traps 66 million tons of sediment per year with consequent impacts on downstream alluvial deposits (McCartney 2000). All major dams in California are accumulating sediment, with many large dams capturing over 90 percent of the load supplied to them (Mount 1995).

Changes in Flow Regime and Downstream Degradation

The reduction in sediment transport in rivers downstream of dams has impacts on channel, floodplain and coastal delta morphology (McCartney 2000), in addition to adversely affecting aquatic species and their habitat. Generally, sediment is transported downstream of a dam as fine grained particles (clay, silt and sand), suspended in the water column (Kondolf 1997). Cobbles and spawning gravel suitable for salmon are often trapped upstream of large dams (American Rivers 2002). Water that passes through a dam is known to be "sediment starved." (American Rivers 2002). Downstream of a dam, sediment-starved rivers often regain sediments lost behind a dam by eroding deeper into the river channel and away at the stream banks. Consequently, the river channel may become coarse, encouraging stream bank erosion and the disappearance of riffles. Below dams, as gravels and finer materials are transported downstream, the streambed may have only substrate material that is too large to be moved by fish to build redds (Kondolf 1997).

Reduction in flow releases from dams can exacerbate channel scouring, a process which may lower groundwater tables and negatively impact riparian habitats. Channel narrowing occurs more frequently downstream of reservoirs that are large enough to contain the river's largest floods (Kondolf 1997). Together, stream bank erosion and channel incision can render the remaining river habitat inhospitable for many organisms, altering the community of species that live in the stream. The effects of river impoundment may extend all the way to coastal areas. Because rivers transport much of the sediments that create coastal habitats, impounding rivers and their sediments can exacerbate the loss of shoreline habitats that depend on continued sediment transport (American Rivers 2002). For example, Henshaw Dam, on the San Luis Rey River, reduced the sediment supply (total sand and gravel yield) to a shoreline area by 2 million tons (Kondolf 1997).

River reaches downstream of a dam are typically degraded. On alluvial rivers surveyed by Williams and Wolman (1984), the channel bed was often degraded[4] in the reach immediately downstream of the dam. Trends observed by Williams and Wolman (1984) indicated that the installation of dams and the consequent decrease of sediment into downstream reaches are primary causes of progressive channel changes. While some channel widths remained constant, other channel widths showed increases of as much as 100 percent or decreases as much as 90 percent (Williams and Wolman 1984). Hundreds of kilometers of river distance downstream from a dam may be required before a river regains, by boundary erosion and tributary sediment contributions, the same annual suspended load or sediment concentration that it transported at any given site prior to dam construction. The distance required is about 200 km to 500 km on rivers such as the North Canadian River downstream from Canton Dam and the Red River downstream of Denison Dam (Williams and Wolman 200). After completion of a dam on a river, the degradation of downstream reaches may take years to reach equilibrium. Initial degradation rates tend to be high, with half the degradation occurring within the first seven years, but complete adjustment could take over 100 years to achieve (Knighton 1998).

Channel incision and degradation of a streambed downstream of a dam may also alter the magnitude, timing, and frequency of floodplain inundation. Ligon et al (1995) noted the river channel downstream of a dam on the Oconee River, had deepened about 1 meter. The new, deeper channel required a higher flow to overtop its banks and spill out on to the floodplain. Consequently, although high flows were not altered by the operations of the dam, the floodplain downstream of the dam appeared to be inundated far less than pre-dam conditions. A reduction in floodplain inundation can often result in a decrease in species diversity and population densities (Ligon et al 1995).

Water releases from a dam typically do not follow a natural flow regime, and, as a result, the river reaches below the dam are significantly altered. A river’s physical and biological characteristics are determined in large part by its flow regime, which refers to the range in magnitude, frequency, and duration of water transport down a river channel and over a set period (i.e. seasonal, year-round). Natural river flows fluctuate according to the season, often with large spring flows corresponding to spring rains or snowmelt, and low summer flows corresponding to warm, dry summer weather (American Rivers 2002). Flow releases from dams are regulated to meet various demands, such as, water supply, navigation, power production, recreation, and flood control (American Rivers 2002). Because of these various purposes for which dams are built and operated, including management of the arrival of floods from upstream, there are large variations from one dam to another in flow releases. Each dam has a unique history of daily, seasonal, and annual flow releases. Whatever the pattern of regulated releases, they are almost certain to be distributed differently than the natural flows (William and Wolman 1984). In stream reaches downstream of a dam, alterations in flow regimes and flow fluctuations can adversely affect fish and other aquatic species.

Altered flow regimes can cause changes in species composition and abundance, and reduced access to side channels, upstream habitat, tributaries, and floodplain habitat. (Stillwater 2006). As discussed above, the inundation of floodplains are important. The reduced frequency of floodplain inundation and changes in the macroinvertebrate community can alter food productivity for fish. In addition to serving as highly productive foraging grounds for many species, inundated floodplains are also important to many fish as a refuge from predation. The reduced availability of this refuge may lead to greatly reduced populations of some forage species which can in turn lead to population declines of

[4] Degradation was defined as a lowering of the mean bed elevation of the channel.

piscivorous fish (Ligon et al 1995).

Low flow releases from a dam may not be high enough for channel maintenance or may not be adequate to trigger the upstream movement of adult salmon (attraction flows). It has been reported that dam construction has resulted in a reduction of the magnitude of flood peaks by as much as 90 percent (Knighton 1998). The reduction of peak flood flows may result in the encroachment of riparian vegetation into parts of the active channel in reaches below a dam (Kondolf 1997, Williams and Wolman 1984). Channel vegetation can reduce channel conveyance, both by physically reducing the flow area near the vegetation and by impeding the sediment transport process. On the Republican River in Nebraska, vegetation decreased the channel capacity by 50 to 60 percent in some reaches (Williams and Wolman 1984)

Peak flows downstream of a dam are needed to flush fine sediment from the riverbed. When peak flows are reduced, fine sediment delivered to the river channel by tributaries may accumulate in spawning gravels, which degrades the quality of the spawning habitat (Kondolf 1997). The reduction of peak flows in downstream reaches affects sediment transport in other ways, as well. Peak flows serve to erode small, nutrient rich sediments from a river and its shoreline, depositing this material downstream and in rich coastal breeding grounds such as estuaries. These same flows transport and redistribute larger sediments and boulders, creating new and more diverse habitat, which is beneficial to aquatic species (American Rivers 2002).

Ligon et al (1995) describe how peak flows affect the process by which flood control dams on the McKenzie River in Oregon are preventing the creation and development of midchannel bars and islands. The existing islands are gradually lost, braided reaches disappear, and the smallest channels are filled in, as the river becomes simplified to an exclusively single-thread channel. These geomorphologic changes could significantly impact the native salmon population by reducing the braided areas where spawning gravels can be deposited, reducing the recruitment of spawning gravel from the floodplain, and reducing areas used by juvenile salmon for rearing habitat and by adult salmon for spawning habitat. In contrast, reduced peak flows below a dam on the Waitaki River in New Zealand cause the riverbed not to shift as often as it did in pre-dam conditions. Further stabilization of the channel has increased as vegetation becomes established on the midchannel bars. Stable channels provide more shelter for salmon fry at high flows.

Although certain peak flows may benefit aquatic species and habitat downstream of a dam, high flow releases, depending on the magnitude and timing of the releases, also could potentially cause adverse effects to the downstream channel or aquatic life. High discharge flow releases could cause bank erosion, channel bed armoring and bed scour downstream of the dam. Changes in discharge and coarse sediment supply associated with a dam may alter number and quantity of salmon spawning sites (redds) significantly. High peak discharges could lead to widespread channel scouring or incision. This could result in the loss of gravel and the development of an armored channel which is not suitable habitat for spawning salmon (Mount 1995).

As described above, the presence of a dam on a river can cause a variety of different geomorphologic responses in the reaches downstream of the dam, depending on factors, such as, the type of river, the type of dam, the pattern of flow releases, and the amount and type of sediment (captured by the dam or brought into the river downstream of the dam). Responses to impoundment of the river can include: incision or aggradation, change in channel pattern (braided rivers become single-thread or vice versa), the streambed becoming coarser or finer, channel widening or narrowing, increased or decreased lateral migration of channels, loss of riparian vegetation, riparian encroachment in active channels, or bank collapse (Ligon et al 1995) .

Loss of Habitat and Impacts to Aquatic Species

The presence of a dam can adversely affect the quality, quantity, and accessibility of spawning, rearing, and foraging habitats for aquatic species. Impoundment may particularly affect species which spawn in relatively fast flowing reaches. The regulation of rivers dampens flow fluctuations which can deprive many fish species of spawning grounds and decrease food supply (Larinier 2000). Flow fluctuations can also result in the loss of access to rearing habitat, such as floodplain and secondary channels. This can lead to changes in species composition, especially the loss of obligate floodplain spawners (Larinier 2000).

Discharges of water downstream of a dam can adversely affect fish in different life stages. Flow fluctuations in downstream reaches can cause stranding of adult or juvenile fish and isolation of redds, which leads to desiccation of eggs. Altered flows can cause changes in the intra gravel oxygen supply which is critical for egg development in redds. High flows can scour spawning gravels and wash away eggs.

Large woody debris (LWD) plays an important role in streams by shaping channel morphology, storing sediment and organic matter, and providing habitat for aquatic species. Salmon may be adversely affected when LWD is trapped in the reservoir behind a large dam. LWD in stream reaches downstream of a dam benefits juvenile salmon by providing cover and protection from predators. The magnitude of a dams’ effect on LWD is a function of the amount of LWD trapped in the reservoir, the potential mobility of that wood, and the distribution of potential depositional zones downstream (Stillwater 2006).

Loss of Habitat Connectivity

Habitat connectivity may be defined as the lateral, longitudinal, and drainage network connections between rivers, reservoirs, and tributaries, that provide chemically and physically unobstructed routes to fulfill life history requirements of aquatic species, including access to intact refugia and opportunities for genetic exchange (Stillwater 2006). Dams, water diversions, reservoirs, stream crossings, and natural features can impact habitat connectivity (Stillwater 2006). A dam can block passage both up- and downstream for migrating fish and other wildlife. This is the case for anadromous fish that migrate between salt and fresh water, as well as for residential fish that move up and down a river to find suitable spawning, rearing and foraging habitat.In addition, dams that fragment the river corridor can isolate populations, sub-populations, and habitats from each other. (Stillwater 2006, American Rivers 2002).

Water Quality and Temperature Changes

Changes in instream water quality are inevitable when free-flowing water becomes impounded (Stillwater 2006). Storage in reservoirs induces physical, chemical and biological changes in the water which affect water quality. The chemical composition of water within a reservoir can be significantly different to that of the inflow. The size of the dam, its location in the river system, its geographical location with respect to altitude and latitude, the detention time of the water and the source(s) of the water all influence the way that storage detention modifies water quality (McCartney 2000). Impoundment of water can cause increased algal growth and reduced water clarity. The sediment within the reservoir can contain metals, toxic compounds, and nutrients from upstream sources, which can degrade the quality of water (Stillwater 2006).

McCartney (2000) proposed that temperature changes caused by water storage have the most significant effect on in-stream biota. Aquatic organisms are directly impacted by temperature. Water temperature directly effects salmonid egg development and survival; determines whether habitat is suitable; drives growth, infection and mortality rates; and increases exposure to both native and non-native aquatic predators better adapted to altered water temperatures (Stillwater 2006). Alterations in water surface area, depth, and velocity due to water diversions into or out of the stream corridor, including reservoir impoundments and conveyance structures, all influence water temperature, which in turn affects biological and ecological processes. In addition, the temperature of the water releases from the dam may be different from the natural temperature regime of the river. The Hume dam on the Murray River, Australia alters the thermal regime of the river and its effect is still discernible 200 km downstream (McCartney 2000).

Reservoirs act as thermal regulators so that seasonal and short-term fluctuations in temperature, that are characteristic of many natural rivers, are dampened. The relatively large mass of still water in reservoirs allows heat storage and produces a characteristic seasonal pattern of thermal behavior. Depending on geographical location, water retained in deep reservoirs has a tendency to become thermally stratified (McCartney 2000). Typically, three thermal layers are formed: i) a warm, well-mixed, upper layer (the epilimnion); ii) a cold, dense, bottom layer (the hypolimnion) and iii) an intermediate layer of maximum temperature gradient (the thermocline). Temperature gradients between the thermal layers may range from 2 – 10 degrees Celsius (McCartney 2000).

In the epilimnion layer, phytoplankton often proliferate and release oxygen thereby maintaining concentrations at near saturation levels for most of the year. During the summer, water released near the surface of a stratified reservoir will not only be well oxygenated, but will also be warm and nutrient depleted (McCartney2000).

In the hypolimnion layer, oxygen depletion may occur, depending on the overall aquatic and upland productivity of the system. Oxygen is used in the decomposition of submerged biomass. Lack of mixing and photosynthesis in the bottom layer also contribute to anoxic conditions. When anoxic conditions occur, the process of organic matter decay becomes anaerobic, and carbon dioxide, methane and hydrogen sulfide are released. In addition, water from this bottom layer may be high in iron and/or manganese. Nutrients, particularly phosphorous, are released biologically and leached from flooded vegetation and soil (McCartney 2000). Releases of impounded water from this hypolimnetic layer can affect downstream populations of fish and other aquatic organisms, including direct mortality of fish below dams, due to the decreased levels of dissolved oxygen; increased levels of metals, nutrients, and turbidity; or altered temperatures (Stillwater 2006).

Depending on the operation of a reservoir, additional chemical changes in water quality may occur. During high water periods, water which spills over the crest of the dam can become over-saturated with oxygen and nitrogen to levels lethal for fish, a harmful physiological condition known as gas bubble trauma. Raymond (1979) reported that high spillway flows produced supersaturation levels that resulted substantial mortalities of both adult and juvenile salmonids downstream of John Day Dam on the Columbia River. In 1994, the Yacyreta dam on the Parana River created supersaturated levels of total dissolved gases that killed fish within a 100 km reach downstream (Larinier 2000).

Other possible chemical changes in water quality due to the impoundment of water include changes in salinity and mercury concentrations. The salinization of water downstream of dams in arid climates (arising from increased evaporation) is particularly problematic and is exacerbated in areas of marine sediments and where saline drainage water from irrigation streams is returned to rivers downstream of dams. Salinization is also a problem on floodplain wetlands where periodic flushing and flood water dilution is absent. If sufficiently high and prolonged, elevated salinity will affect aquatic organisms (McCartney 2000).

Changes in mercury concentrations can also be a major reservoir problem. In many soils, mercury is naturally present in a harmless inorganic form. However, bacteria breaking down decomposing matter in reservoirs transform this inorganic mercury into methylmercury, a toxin of the central nervous system. Plankton and other creatures at the bottom of the aquatic food chain absorb the methylmercury. As the methylmercury passes up the food chain it becomes increasingly concentrated in the bodies of the animals eating contaminated prey. Through this process of bio-accumulation, levels of methylmercury in the tissues of large fish-eating fish at the top of the food-chain can be several times higher than in the small organisms at the bottom of the chain (McCartney 2000).

Greenhouse Gas Emissions (Carbon Dioxide and Methane Gas)

Freshwater lakes are capable of releasing far more carbon into the atmosphere than they absorb (PPS Systems 2008). Reservoirs are also known to release greenhouse gases (PPS Systems 2008). Terrestrial vegetation once submerged ceases to function as a sink for atmospheric carbon dioxide (CO_2) and undergoes microbial decomposition, releasing both CO_2 and methane (CH_4). The global-warming potential of CH_4 is 20-40 times that of CO_2 (per g basis), so the percentage of CH_4 released is important (Rosenberg 1997).

The following factors may be involved in regulating the intensity and duration of greenhouse gas emissions after reservoir creation (Rosenberg 1997).

1. The amount of flooding involved. Extensive flooding of terrestrial areas will lead to large releases of gases.
2. The age of the reservoir. Decomposition rates appear to decrease with time, as indicated by data on oxygen depletion (Rosenberg 1997). An initial period of rapid decomposition of easily degraded organic material probably will be followed by a period of slower decomposition of more refractory organic material. The slowing of rates means that the longer the life of a reservoir, the lower will be the average flux per year of gases. However, even after decomposition of organic material is complete, greenhouse gas emissions will be similar to the rates produced by natural lakes, which are greater than estimated fluxes for the original, undisturbed, terrestrial system (Rosenberg 1997).
3. The amount of plant biomass and soil carbon flooded. Plant biomass varies in different ecosystems and so does soil carbon (Rosenberg 1997).
4. The geographic location of a reservoir. Temperature will vary with location, and temperature will affect the rate of decomposition and the ratio of CH_4:CO_2 that is released. Tropical reservoirs will have high water temperatures and fast decomposition, which tend to produce anoxic

conditions and a high proportion of CH_4 (Rosenberg 1997). Flooding of peat soils is of special concern because the large amount of carbon stored in them could produce greenhouse gases for decades (Rosenberg 1997).

Juvenile Mortality at Turbines and Spillways

Downstream migrating fish typically pass through a hydropower facility either through turbines, sluiceways, spillways, or a bypass channel or other water conveyance system. As fish swim close to the hydropower facilities they may become entrained[5], and thereby move from a reservoir through the water conveyances at the dam to a downstream exit. Entrainment effects can occur at various project facilities, including spillways, turbines, fish ladders, and downstream fish bypass facilities(Stillwater 2006).

Fish passing through a hydropower facility can be injured or killed from the stresses they encounter. For example, fish may experience shocks from moving or stationary parts of a turbine, sudden acceleration or deceleration, or from variation in pressure as well as cavitation.

Mortality and injury rates differ depending on whether fish pass through a spillway or through a turbine. Successful passage also depends on the type of turbine (e.g. Francis or Kaplan). Numerous experiments have been conducted in various countries, including the U.S., Canada, Sweden, Netherlands, Germany and France, mainly on juvenile salmonids and less frequently on clupeids and eels, to determine the mortality rate due to their passage through turbines (Larnier 2000). The mortality rate for juvenile salmonids in Francis and Kaplan turbines varies greatly, depending on the properties of the wheel (diameter, speed of rotation, etc), their conditions of operation, and the head. The species and size of fish also affect the level of stress or physical mortality. For example, some species of fish lack swim bladders, while others have open (physostomous) or closed (physoclist) swim bladders. The risk of rupturing the swim bladder following a sudden drop in pressure is significant for physoclistic fish, which are susceptible to variations in pressure (Larinier 2000). Migratory fish species, such as salmon and lamprey, are especially affected as they need to migrate downstream to successfully complete their life cycle (Stillwater 2006).

Fish passing through turbines may be particularly susceptible to disease or predation due to disorientation and fatigue. On the Columbia River, predator exposure associated with turbine passage is known to be major cause of salmon mortality. Tests at the Kaplan turbines indicated a mean loss of 7% but studies showed that mortality of juvenile Coho salmon could reach 30% when indirect mortality from predation was included (Larinier 2000).

Fish passing through spillways may be killed or injured by: shearing effects, abrasion against spillway surfaces, turbulence in the stilling basin at the base of the dam, sudden variations in velocity and pressure as the fish hits the water, and physical impact against energy dissipaters. The manner in which energy is dissipated in the spillway can have a determinant effect on fish mortality rates (Larinier 2000).

[5] Fish entrainment is defined as “the incidental trapping of any life stage of fish within waterways or structures that carry water being diverted for anthropogenic use” (NMFS 2010).

Passage through a spillway under free-fall conditions (i.e. free from the column of water) is always less hazardous for small fish. For larger fish, the hazards are identical whether they pass under free-fall conditions or are contained in the column of water. “Ski jump” spillways are preferable to other types of spillways, because the abrasion on the spillway face is eliminated. Passage is generally less hazardous for fish if there is a pool of sufficient volume at the base of the spillway (Larinier 2000).

In addition to the problems associated with turbines discussed above, upstream migrating fish may be adversely affected by turbines. Upstream migrants can be delayed in project tailraces and fish ladders. Adult fish moving upstream could also be injured in draft tubes (exit for turbine discharge) when they attempt to enter the draft tubes because of a false attraction to the discharge, or to use the draft tubes as “cover.” Injury and delay associated with turbines are observed typically under the following circumstances:

- turbine discharge has better water quality than mainstem river,
- turbine discharge is a large proportion of total flow,
- turbine discharge is rapidly changing,
- fish ladders are too long, or
- fish are imprinted[6] on water from turbine discharge. (Stillwater 2006).

For a further discussion of different types of turbines and the effects of turbines on migrating fish, see the Fish Passage Technologies section.

Loss of Nutrients — Salmon Carcasses

Pacific salmon spend most of their life cycles as top predators in the nutrient-rich North Pacific Ocean, where they incorporate carbon, nitrogen, phosphorus, and other micronutrients into their body tissues (Merz 2006). Each year, salmon bring back significant amounts of these nutrients to the aquatic ecosystems where they spawn and die (Wipfli 2010). When dams prevent salmon from accessing historical spawning areas, those areas could suffer from a nutrient deficit because of the decreases in salmon carcasses (Wipfli 2010). This loss of marine derived biomass may be causing large declines in aquatic and riparian productivity (Wipfli.2010)

Spawning salmon release nutrients into streams through normal metabolic processes, release of gametes, consumption of salmon flesh by predators and scavengers, and decay of carcasses (Merz 2006). Merz et al. investigated the transfer of marine derived nutrients from salmon carcasses to adjacent forest ecosystems in two modified rivers: one with (Mokelumne River) and one without (Calaveras River) consistent salmon runs. The results of this study suggest that robust salmon runs continue to provide important ecological services with high economic value, even in impaired watersheds (Merz 2006).

Attempts to restore lost nutrients and productivity in streams have included adding hatchery salmon carcasses, carcass analogs, and artificial fertilizers (nutrient pellets) to streams (Wipfli 2010). While artificial nutrient additions and fertilization programs have been successful at increasing aquatic productivity and fish production in some cases (Wipfli 2010), the comparative effects of enrichment from artificial nutrient additions versus salmon carcasses have not been investigated. Artificial nutrient

[6] Salmonids are imprinted on their natal streams, and as adults, use the “smell” of the water to return to their natal streams.

amendments lack carbon, which may explain the breadth and magnitude of stream food web responses to salmon carcasses (Wipfli 2010). Lipids, protein, and other carbon-based macromolecules may be critically important for the nutritional health and productivity of aquatic ecosystems (Wipfli 2010).

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Fish Migration

Migration behavior is widespread among fishes. However, only a relatively small number of about 230–250 fish species are known to be diadromous, in which some fish species migrate from freshwater, where they are born, and spend their adult life in the ocean (anadromous species) and others migrate from the ocean, where they are born, and spend their adult life in freshwater (catadromous) (McDowall 1999).

Many of these migratory fish are of great historic and/or economic interest (e.g. salmonids, sturgeons, eels) and therefore well studied (McDowall 1988). Others are less well-known and there is insufficient knowledge about their migration patterns (e.g. some shads, grey mullets, gobies). During their life histories, diadromous fish travel, and use, a wide range of fresh water and marine as well as estuarine habitats, and often cross several international borders (McDowall 1999).

Due to their migratory behavior, diadromous fish have been identified as being at a generally higher risk of extinction that many other groups. Whereas approximately 5% of all fish species are considered endangered, threatened, vulnerable, rare, or of indeterminate status (Barbault and Sastrapradja 1995), McDowall (1999) has identified about 18% of diadromous species that are of some conservation concern. One group, the sturgeons (Acipenser spp.), are particularly imperiled, both in Europe and Asia (Jonsson 1999).

On the West Coast, anadromous salmon and steelhead populations have been adversely affected by the construction of large dams (West Coast Chinook Salmon Biological Review Team 1997). Many populations of salmonids have declined to the extent that they are listed as threatened, endangered, or a species of concern under the federal Endangered Species Act (ESA) and California Endangered Species Act. For Pacific salmon, the National Marine Fisheries Service (NOAA Fisheries) considers an evolutionarily significant unit (ESU) a "species"[7] under the ESA. NOAA Fisheries has designated 17 separate ESUs for Chinook salmon, ten of which are listed. There are seven ESUs for Coho salmon; five are listed. For Pacific steelhead, NOAA Fisheries has delineated 15 distinct population segments (DPS) for consideration as "species"[8] under the ESA (NOAA Fisheries 2011); 12 are listed.

In California, 14 anadromous fishes, with numerous independent runs, spawn in coastal streams and rivers (Moyle 2002). Species include: sturgeon (white and green), striped bass, American shad, stickleback and pacific lamprey, among others. Three species of Pacific salmonids are native to California: Chinook (Oncorhynchus tshawytscha), Coho (Oncorhynchus kisutch), and Steelhead (Oncorhynchus mykiss). Approximately 47% of California's salmonids are recognized as threatened, endangered, or extinct by state and federal governments (Moyle 2009). Table 3 summarizes the current status of these fish populations (NOAA Fisheries 2011).

Table 3: Current Status of Listed Anadromous Fish in California

Species (ESU or DPS)		Current Federal ESA Listing Status
Chinook Salmon	California Coast Chinook Salmon	Threatened

[7] The Endangered Species Act (ESA) defines a "species" to include any distinct population segment of any species of vertebrate fish or wildlife (NOAA Fisheries 2011).

	Sacramento River Winter-run Chinook	Endangered
	Central Valley Fall and Late Fall-run Chinook	Species of Concern
	Central Valley Spring-run Chinook	Threatened
Coho Salmon	Southern Oregon/Northern California Coast Coho	Threatened
	Central California Coast Coho	Endangered
Steelhead	Northern California Coast Steelhead	Threatened
	Central California Coast Steelhead	Threatened
	California Central Valley Steelhead	Threatened
	South-Central Coast Steelhead	Threatened
	Southern California Steelhead	Endangered
Green Sturgeon	Southern DPS of North American Green Sturgeon	Threatened

Source: NOAA Fisheries 2011.

The California Department of Water Resources Proposition 84 System Reoperation studies are focused on flood control and water supply infrastructure (including large dams and reservoirs) in California's Central Valley. Because this infrastructure has had a profound effect on aquatic ecosystems, the greatest potential for ecosystem restoration through reoperation is also found in the Central Valley (DWR 2011). Therefore, this report provides additional information on the current and historical habitat of the three listed anadromous species which are most affected by the presence of large dams on Central Valley rivers: Chinook salmon, steelhead, and green sturgeon (*Acipenser medirostris*).

Listed Anadromous Fish in the Central Valley

Anadromous fish hatch from eggs laid in freshwater streams, migrate as juveniles to saltwater, and after living and growing in ocean waters then return as adults to spawn in freshwater to complete their life cycle.

California Chinook salmon are similar in morphology and are distinguished mainly by genetic and life history traits (e.g., run timing) (Moyle et al. 2008). The distinct populations within the species generally referred to as "runs" or "stocks," are named after the season in which they begin their fresh-water spawning migrations, and are genetically and geographically distinct.

In California's Central Valley, there are four genetically distinct runs: fall, late-fall, winter, and spring.

Steelhead in California occur in six populations[8] (Evolutionarily Significant Units (ESU) and Distinct Population Segments (DPS)) recognized by NOAA Fisheries. The populations are morphologically identical to one another and are distinguished by genetic characteristics. California populations of steelhead have complex systematic relationships (Moyle 2002), and while California's six populations have essentially discrete geographic boundaries, adjacent populations have some degree of genetic

[8] For Pacific salmon, NOAA Fisheries Service considers an evolutionarily significant unit (ESU) a "species" under the ESA. For Pacific steelhead, NOAA Fisheries Service has delineated distinct population segments (DPS) for consideration as "species" under the ESA (NOAA Fisheries, 2009).

similarity. The DPS of steelhead which is distributed in the Central Valley is the California Central Valley Steelhead.

Sturgeon occur in temperate waters throughout the Northern Hemisphere. Twenty-five species are currently extant, of which eight species are found in North America, and only two occur in California: white sturgeon (*Acipenser transmontanus*) and green sturgeon (Moyle, 2002). On the basis of genetic analyses and evidence of spawning site fidelity, NOAA-Fisheries determined that green sturgeon occur in at least two DPS (Adams et al. 2002): a "Northern DPS" consisting of populations from coastal watersheds northward of and including the Eel River, and a "Southern DPS" consisting of populations from Coastal California and Central Valley watersheds south of the Eel River (NOAA Fisheries 2010a, 2010b).

Table 4 summarizes the timing of the life stages of steelhead, green sturgeon, and the four runs of Chinook salmon in the Central Valley.

Table 4: Life Stage Timing for Anadromous Fish in the Central Valley

Species	Adult Immigration	Adult Holding	Typical Spawning	Egg Incubation	Juvenile Rearing	Juvenile Emigration
Winter-run Chinook salmon	December – July	January – May	April – August	April – October	July – March	July – March
Spring-run Chinook salmon	April – July	May – September	August – October	August – December	October – April	October - May
Fall-run Chinook salmon	July – December	n/a	October – December	October - March	December – June	December – July
Late Fall-run Chinook salmon	October – April	n/a	January – April	January – June	April – November	April – December
Steelhead	August – March	September – December	December – April	December – Jun	Year round	January – October
Green sturgeon	February – June	June – November	March – July	April – June	May – August	May – December

Source: NOAA Fisheries, 2009b.

Historic and Current Populations of Listed Anadromous Fish in the Central Valley

Spring-Run Chinook

The basic life history of spring-run Chinook salmon is to migrate upstream in spring, hold through the summer in deep, cold water pools, and then spawn in early fall, with juveniles emigrating after either a few months or a year of rearing in fresh water.

Lindley et al. (2004) identified 26 historical populations within the spring-run Chinook salmon ESU; 19 were independent[9] populations, and seven were dependent populations. Only three independent populations of spring-run Chinook that occurred historically are extant, in Deer, Mill, and Butte creeks

[9] Lindley (2006) defines independent populations as "any collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period is not substantially altered by exchanges of individuals with other populations." Lindley et al. (2004) used several characteristics, including distance from a basin to its nearest neighbor (at least 50 km), the basin size (generally at least 500 km^2), and significant environmental differences between basins inside of the distance criterion, as well as data on population genetics and dynamics to decide whether populations were independent or dependent.

(in Tehama and Butte counties). Nine extant dependent populations occur in Battle, Antelope, Big Chico, Clear, Beegum, and Thomes Creeks, as well as in the Yuba River, the Feather River below Oroville Dam, and in the mainstem Sacramento River below Keswick Dam (NOAA Fisheries, 2009a) (Figure 2). Within these regions, Chinook distribution is determined by water temperature and accessibility of spawning, rearing, and holding habitats (Moyle et al. 2008).

Blockage of upstream summer holding habitat has created a greater potential for spring-run salmon to hybridize with other runs because the runs are no longer spatially and temporally separated (DWR 2005). The Feather River population depends on the Feather River Fish Hatchery production, and is likely hybridized with fall-run Chinook salmon.

Little is known about the status of the spring-run Chinook salmon population in the lower Yuba River, although the installation of a Vaki Riverwatcher system at Daguerre Point Dam is providing more accurate estimates of population size. The upper Sacramento River may support a small spring-run Chinook salmon population, but that population is likely to be highly hybridized with fall-run Chinook salmon, and the status of that population is poorly documented (NOAA Fisheries 2009a).

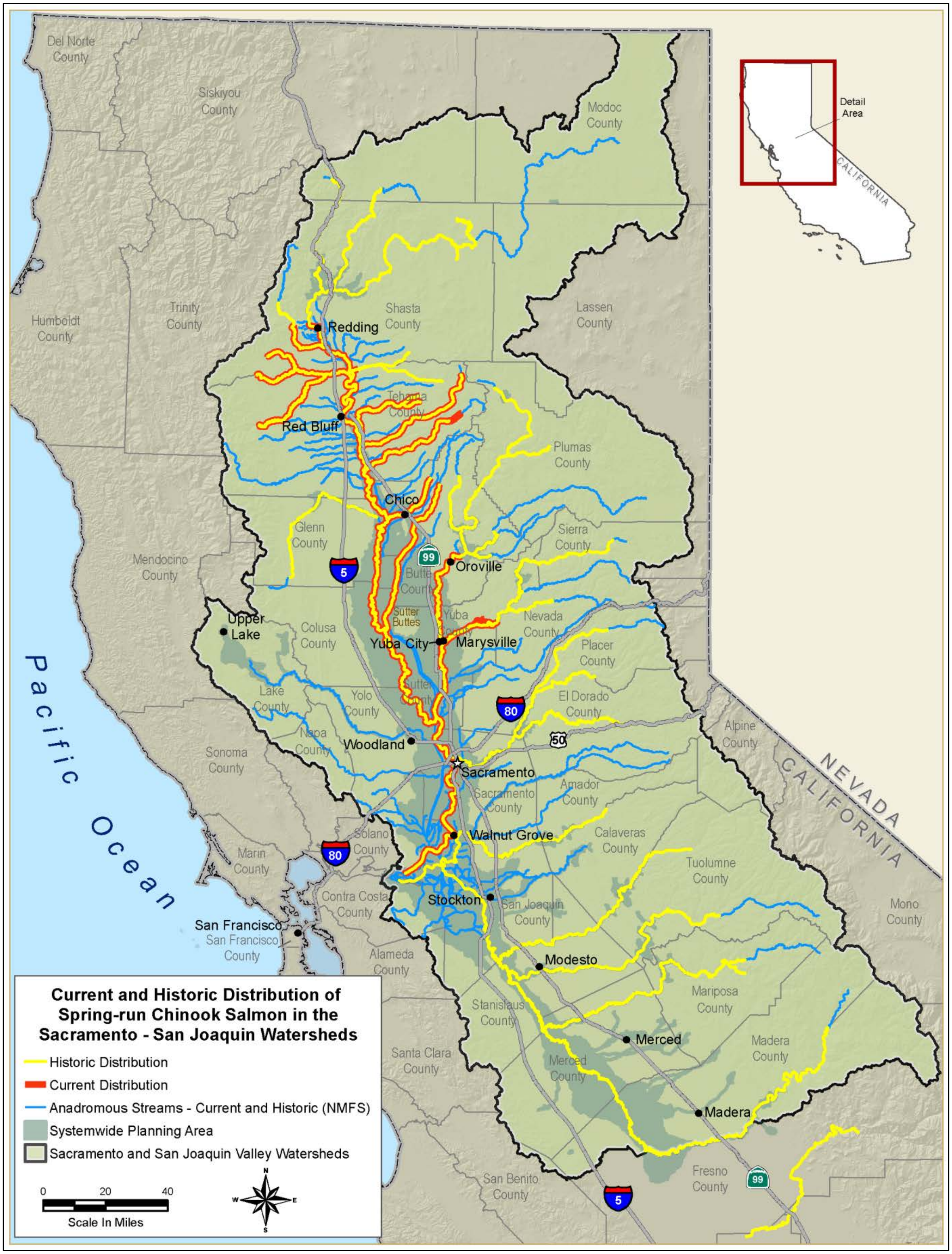

Figure 2: Current and Historical Spring-Run Chinook Salmon Distribution

Since 1970, Central Valley spring-run Chinook salmon population levels have fluctuated significantly from highs near 30,000 fish to lows near 3,000. According to NOAA Fisheries, the 5-year average spring-run Chinook salmon population size in the late 1990s was 8,500 fish, compared with 40,000 fish in the 1940s (DWR 2005) (Figure 3).

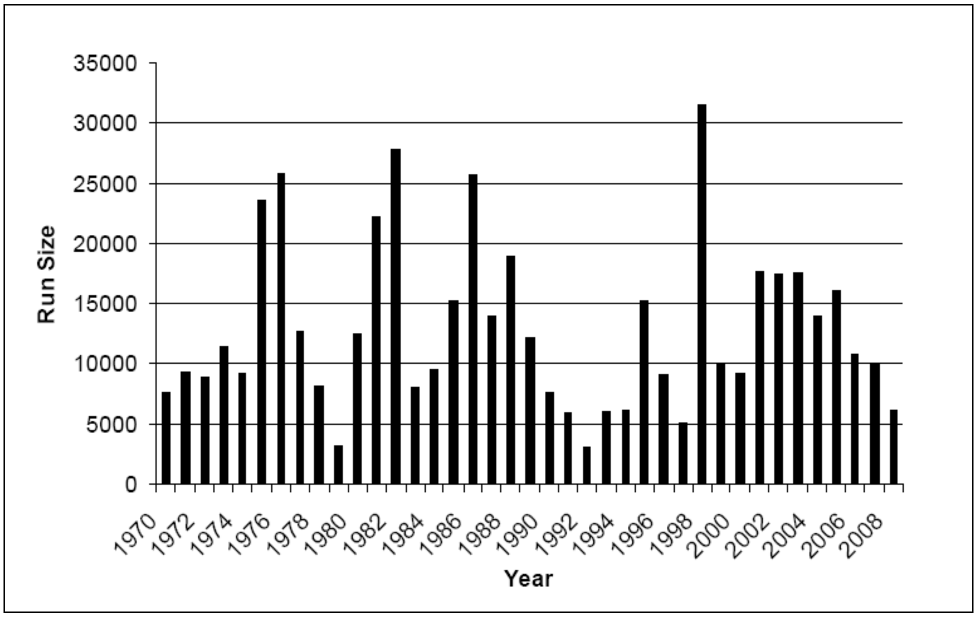

Figure 3: Estimated Spring-Run Chinook Salmon Run Size (1970 – 2008)
(Source: NOAA Fisheries, 2009a)

Sacramento River Winter-Run Salmon

Sacramento River winter-run Chinook salmon have a life history that differs considerably in its timing from the other three Central Valley runs. Their spawning migration lasts from December to May, with runs peaking in mid-March. They enter fresh water as sexually immature adults and migrate to the Sacramento River downstream from Keswick Dam, where they hold for several months until spawning from April through early August (Moyle et al. 2008).

Most winter-run fry emigrate past Red Bluff Diversion Dam (RBDD) in summer or early fall (Moyle et al. 2008), but many rear in the river below Red Bluff for several months before they reach the Sacramento-San Joaquin (Delta) in early winter. Juveniles enter the Delta from January to April where they complete smoltification and migrate to the ocean to mature (Moyle et al. 2008).

Historically, there were four independent populations of winter-run Chinook salmon: Little Sacramento River, Pit River-Fall River-Hat Creek, McCloud River, and Battle Creek (Figure 4). The first three of these areas are blocked by Shasta and Keswick dams (Lindley et al. 2004). Winter-run Chinook salmon no longer inhabit Battle Creek as a self-sustaining population, probably because hydropower operations make conditions for eggs and fry unsuitable (Lindley et al. 2007). In addition, access to much of the basin was blocked until recently by the Coleman National Fish Hatchery (CNFH) barrier weir (Lindley et al. 2007). However, a collaborative partnership (including state and federal resource agencies, Pacific Gas and Electric Company, public watershed groups, and other stakeholders) is currently implementing the Battle Creek Salmon and Steelhead Restoration Project. This restoration project is removing five dams on Battle Creek, installing fish screens and ladders on three dams, and ending the diversion of water from the North Fork to the South Fork (NOAA Fisheries 2011). Upon its completion, the project will reestablish approximately 42 miles of winter-run and spring-run Chinook salmon and steelhead habitat on Battle Creek, plus an additional six miles on its tributaries. For information, see: http://www.usbr.gov/mp/battlecreek/index.html (Reclamation 2011a).

Currently, there is one independent population of winter-run Chinook salmon inhabiting the area of cool water between Keswick Dam and Red Bluff, where cold-water releases from Shasta Reservoir, combined with artificial gravel additions, have created suitable habitat (Moyle et al. 2008). This area was not historically used by winter-run Chinook salmon for spawning (Lindley et al. 2004). Winter-run Chinook salmon have avoided hybridization with fall-run Chinook in this area, unlike spring-run Chinook salmon, due to their temporal isolation from the fall-run salmon.

The U.S. Fish and Wildlife Service (USFWS) manages a conservation hatchery program for winter-run Chinook salmon which is located at the Livingston Stone National Fish Hatchery. This hatchery program supplements the natural population according to strict guidelines developed in conjunction with NOAA Fisheries. Based on a review of available genetic and other information, this hatchery stock was considered part of the Sacramento River winter-run Chinook ESU and was listed in 2005 (NOAA Fisheries 2011).

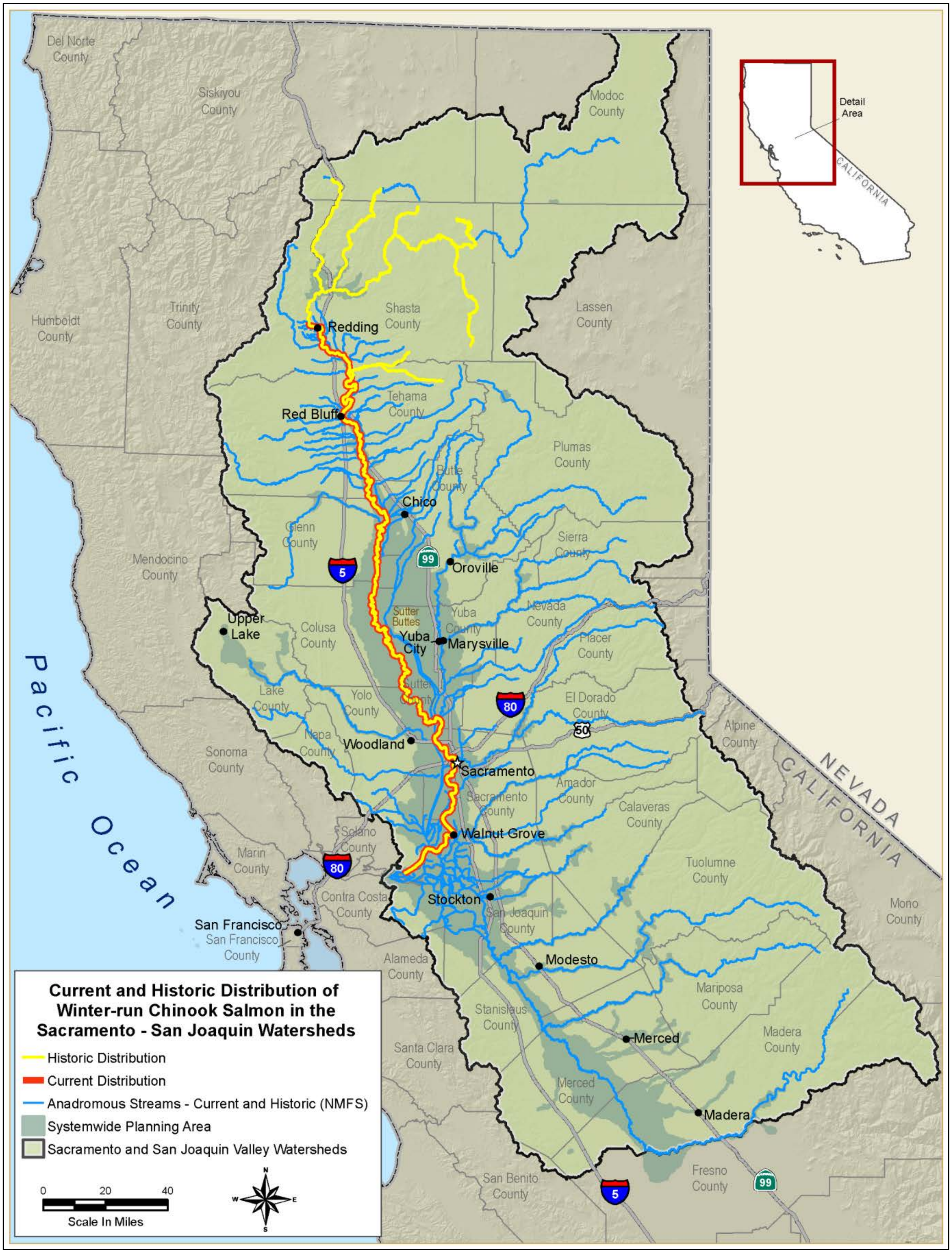

Figure 4: Current and Historical Winter-Run Chinook Salmon Distribution

Since the mid-1990s the population of winter-run Chinook salmon that spawns below Keswick Dam has been increasing, although it has yet to reach 1970 levels (Figure 5). Recently, the population of winter-run Chinook has decreased. From December 2010 to August 2010, escapement for winter-run Chinook salmon in the Central Valley was only 1,533 (NOAA Fisheries 2011). NOAA Fisheries (2011) indicates that the current population trend for the winter-run Chinook ESU is declining.

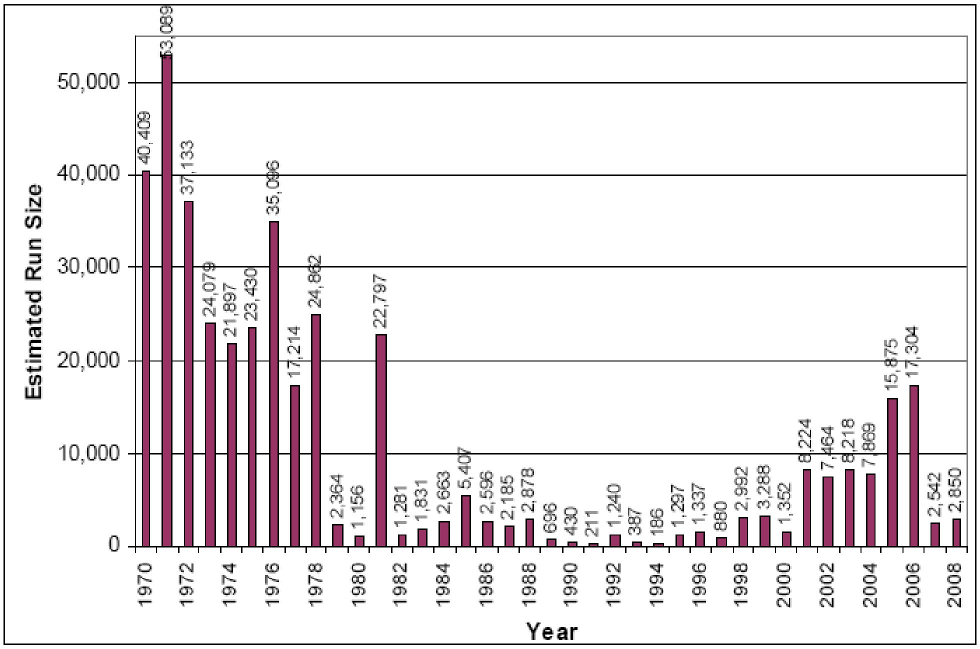

Figure 5: Estimated Sacramento Winter-Run Chinook Salmon Run Size (1970 – 2008) (Source: NOAA Fisheries 2009a)

Fall Run Chinook Salmon

Central Valley fall-run Chinook salmon primarily migrate upstream in the fall as mature fish, although they have been recorded migrating from June through December, and a portion of the population returns as immature fish (Moyle et al. 2008). Peak spawning time is typically in October through November but can continue through December. Juveniles mostly emerge in December through March and rear in natal streams for 1 to 7 months, usually moving downstream into the main rivers within a few weeks after emerging and then enter the San Francisco Estuary as both fry and smolts (Moyle et al. 2008).

Using modern genetic techniques, late-fall-run Chinook salmon are distinguishable from the other runs, although late-fall-run Chinook were only recognized as a distinct run in 1966 after the construction of the Red Bluff Diversion Dam (Williams 2006). NOAA Fisheries manages late-fall-run Chinook as part of the Central Valley fall-run ESU because of their close relationship to it (Moyle et al. 2008).

Central Valley fall-run Chinook salmon historically spawned in all major rivers of the Central Valley, migrating as far south as the Kings River, and north to the upper Sacramento, McCloud, and Pit rivers (Figure 6). There were also small, presumably intermittent, runs in smaller streams such as Putah and Cache creeks.

A large portion of the fall-run Chinook salmon population contributing to ocean fisheries is raised in hatcheries, including Feather River Hatchery, Mokelumne River Hatchery, Coleman National Fish Hatchery on Battle Creek, and Nimbus Hatchery on the American River (Lindley et al. 2009).

Currently, fall-run Chinook salmon spawn upstream as far as the first impassible dam (e.g., Keswick Dam on the Sacramento River), although on the San Joaquin side of the Central Valley they only reach the Merced River because Friant Dam has cut off all natural flows to the lower San Joaquin River (Moyle et al. 2008). Restoration in the San Joaquin River is ongoing. In the upper Sacramento River, the relative proportions of fall-run spawning in the mainstem and in Battle Creek have approximately reversed over the last half-century, with more fish now spawning in Battle Creek than in the Sacramento River upstream of Red Bluff (Williams 2006).

Spawning populations of late-fall-run Chinook salmon occur in several tributaries of the Sacramento River, including Battle, Cottonwood, Clear and Mill creeks, and in the Feather and Yuba rivers (Stillwater 2007). However, the sizes of these spawning populations are relatively small, with the exception of Battle Creek where late-fall-run Chinook are artificially propagated at the Coleman National Fish Hatchery (Stillwater 2007).

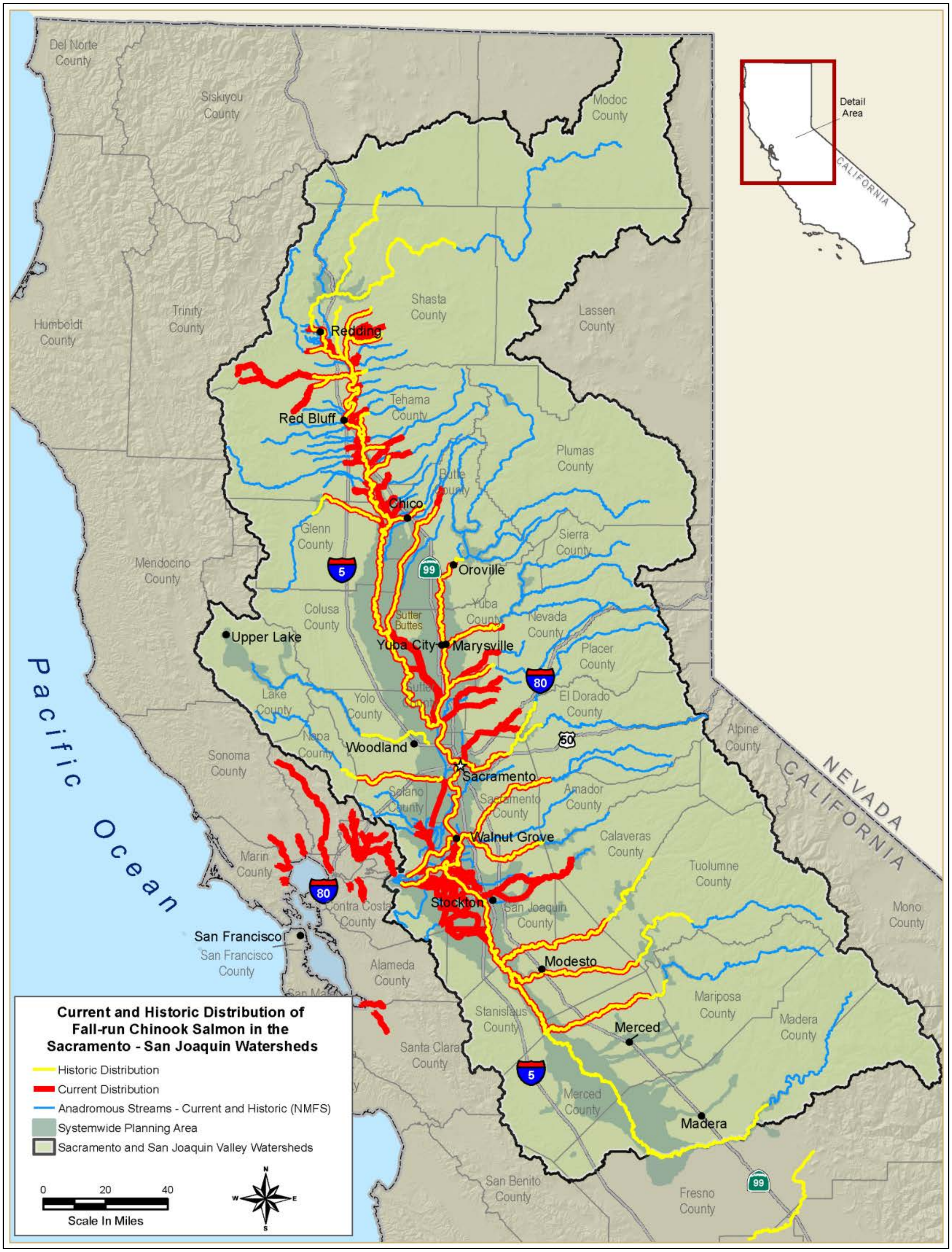

Figure 6: Current and Historical Fall-Run Chinook Salmon Distribution

Fall-run Chinook have always been the most abundant salmon run in the Central Valley (Moyle 2002). From the 1870s through the early 1900s, annual in-river harvest in the Central Valley often totaled 4 million to 10 million pounds of Chinook, approaching or exceeding the total annual harvest by statewide ocean fisheries in recent decades. Maximum annual stock size (including harvest) of Central Valley Chinook salmon before the twentieth century has been estimated conservatively at 1 million to 2 million spawners with fall-run salmon totals perhaps reaching 900,000 fish (Yoshiyama et al. 1998). Annual escapement of fall-run Chinook salmon has remained relatively stable from the 1960s through the 1990s, totaling between 100,000 and 350,000 adults per year. However, escapement began to fluctuate more erratically in the present decade, climbing to a peak of 775,000 in 2002 but then falling rapidly to near-record lows in 2007 (estimated spawning escapement of 88,000) (Figure 7) (Lindley et al. 2009).

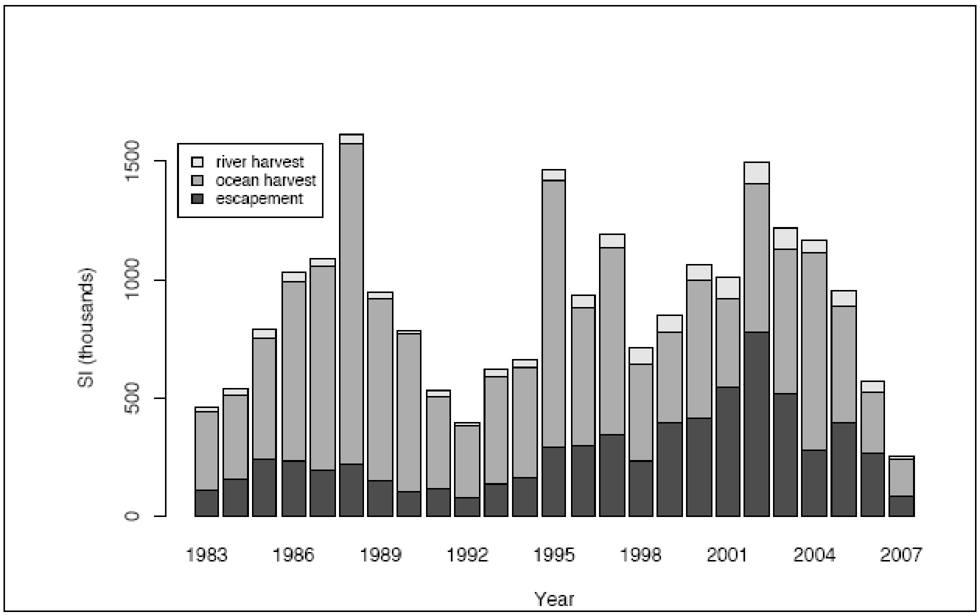

Figure 7: Sacramento River Fall-Run Chinook Escapement, Ocean Harvest, and River Harvest (1983 – 2007) (*Source: Lindley et al., 2009)*

Central Valley Steelhead

Steelhead and rainbow trout are the same species, with steelhead referring to the anadromous form of the species. Central Valley steelhead typically begin their spawning migration in fall, winter, and spring, and spawn relatively soon after freshwater entry. Spawning occurs January through March, but can extend into spring and possibly early summer months (McEwan 2001). Rearing takes place during the summer and juvenile steelhead emigrate from natal streams during fall, winter, and spring high flows (NOAA Fisheries 2009b).

Historically, Central Valley steelhead were distributed throughout the Sacramento and San Joaquin rivers (McEwan 2001). Steelhead were found from the upper Sacramento and Pit rivers (both now inaccessible due to Shasta and Keswick dams) south to the Kings and possibly the Kern River systems, and in both east- and west-side Sacramento River tributaries (NOAA Fisheries 2009b).

Naturally spawning stocks of steelhead are currently known to occur in the Sacramento River and tributaries, Mill, Deer, Antelope, and Butte creeks, and the Feather, Yuba, American, Mokelumne, Calaveras, and Stanislaus rivers. Steelhead smolts have been found in Auburn Ravine, Dry Creek, and have been monitored in the Stanislaus River since 2003 (Figure 8) (McEwan 2001; FISHBIO Environmental, 2011; NOAA Fisheries 2009a). Steelhead are also present in the Tuolumne River, Merced River, and Cow, Battle, Cottonwood, Clear, and Big Chico creeks (DWR 2005; NOAA Fisheries 2009a).

Naturally spawning populations may exist in many other streams but are undetected due to lack of monitoring programs (NOAA Fisheries 2009b). According to Lindley et al. (2006), there are approximately 81 independent populations of steelhead in the Central Valley.

Four hatcheries raise steelhead in the Central Valley, producing an average 1.5 million yearlings per year: Feather River Hatchery, Mokelumne River Hatchery, Coleman National Fish Hatchery on Battle Creek, and Nimbus Hatchery on the American River (Moyle et al. 2008).

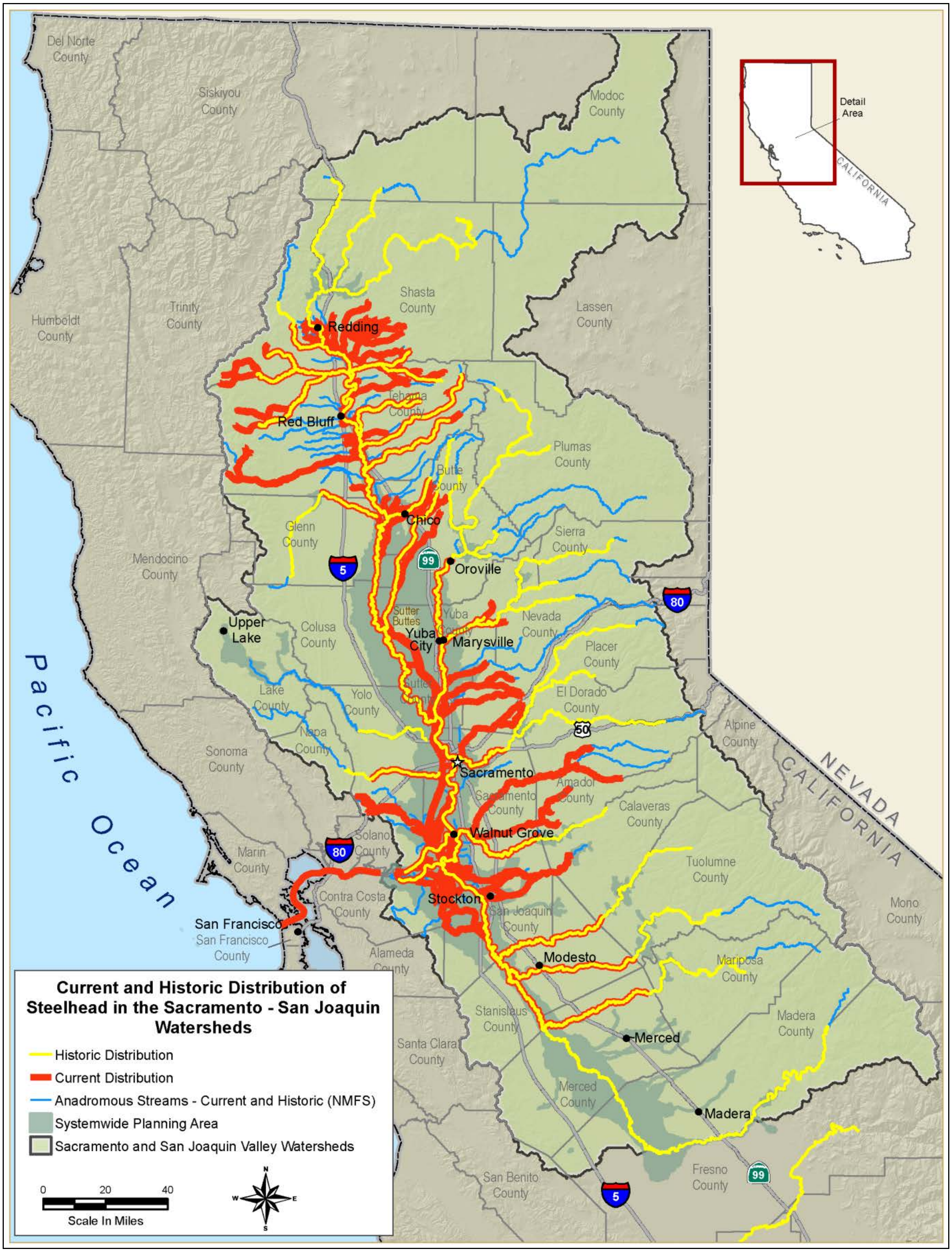

Figure 8: Current and Historical Central Valley Steelhead Distribution

Steelhead counts at the Red Bluff Diversion Dam on the Sacramento River provide an indicator of the magnitude of the decline of Central Valley hatchery and wild steelhead stocks (Figure 9). Steelhead counts declined from an average annual count of 11,187 adults for the 10-year period beginning in 1967, to 2,202 adults annually in the 1990s (McEwan 2001).

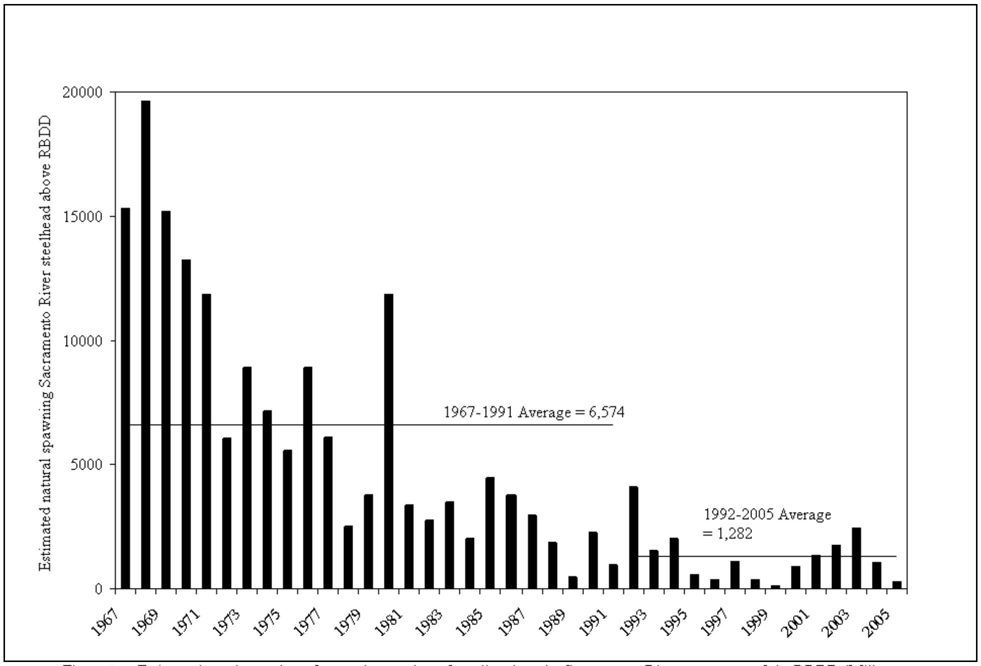

Figure 3 Estimated yearly number of natural spawning of steelhead on the Sacramento River, upstream of the RBDD (Mills

Figure 9: Steelhead Population Trends in the Sacramento River, Upstream from Red Bluff Diversion Dam from 1967 to 2005 (Source: Moyle et al., 2008.)

Green Sturgeon

Although the timing and location of spawning for green sturgeon is less well known than for salmon, recent studies have provided additional information (Poytress et al. 2010; Poytress et al. 2011). Heublein et al. (2009) describes the timing and movement patterns of migrating green sturgeon and identifies likely spawning reaches. Upstream migration of adult green sturgeon appears to begin in February and lasts until late July (Stillwater 2007). Green sturgeon spawn between March and July in the mainstem Sacramento River as far upstream as Keswick Dam. Adult sturgeon are found in the Delta and the San Francisco Bay Estuary, including northern San Francisco, San Pablo, and Suisun Bays, from March, or earlier, through October (Kelly et al. 2007), with some individuals outmigrating from the Sacramento River in December and February (NOAA Fisheries, 2010a).

Green sturgeon larvae begin to emerge and move downstream in May, with peak passage occurring at Red Bluff Diversion Dam in June and July (Stillwater 2007). Green sturgeon juveniles rear in the Sacramento River and the Delta and bays for 1 to 4 years before migrating out to sea as subadults (NOAA Fisheries, 2010a).

Spawning, rearing, feeding, and migratory habitat for all life stages of green sturgeon found within the Central Valley include the following estuaries, bays, and freshwater rivers and streams within the Central Valley: the Delta; the San Francisco, San Pablo, and Suisun bays; the Sacramento River upstream to Keswick Dam (River Kilometer (RK) 483); the lower Feather River upstream to Oroville

Dam (RK 116); and the lower Yuba River upstream to the Daguerre Point Dam (RK 19)(NOAA Fisheries 2010a). Designated Critical Habitat of green sturgeon is shown on Figure 10.

Population abundance information for green sturgeon is limited (Beamesderfer 2002; Adams et al. 2002; NOAA Fisheries 2005; Beamesderfer 2007). In terms of overall annual relative abundance, it appears that green sturgeon populations declined from 1995 to 1999 and then remained relatively stable from 2002 to 2006 (Stillwater 2007).

Upstream of Red Bluff Diversion Dam, Israel (2006) estimated a maximum spawning population of 32 spawners in 2002, 64 in 2003, 44 in 2004, 92 in 2005, and 124 in 2006 (with an average of 71) (NOAA Fisheries, 2009b). Below Red Bluff Diversion Dam, green sturgeon larvae were captured in rotary screw traps: 517 individuals in 1994 and 291 individuals were captured between 1996 and 2000 (Heublein et al. 2009).

Abundance information has also been collected at two DWR facilities, the John E. Skinner Fish Facility and the Harvey O. Banks Pumping Plant. Abundance data for green sturgeon were recorded at the John E. Skinner Fish Facility in Tracy between 1968 and 2001. The average number of green sturgeon entrained per year at the facility before 1986 was 732; from 1986 on, the average per year was 47. At the Harvey O. Banks Pumping Plant, the average number of green sturgeon entrained per year before 1986 was 889; from 1986 to 2001, the average was 32 (NOAA Fisheries 2009b).

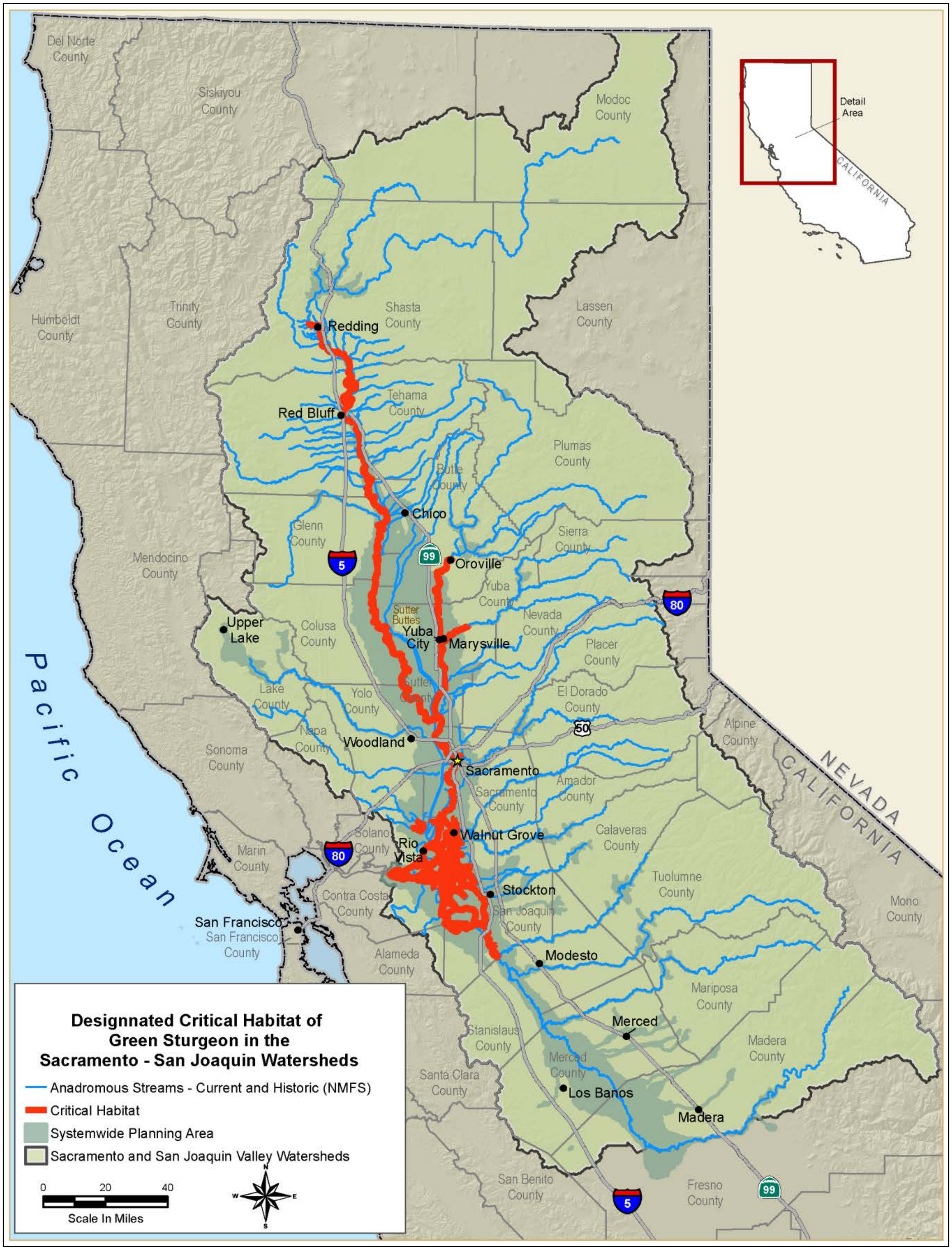

Figure 10. Critical Habitat for Green Sturgeon in the Central Valley

The Decline in Anadromous Fish Populations

Several factors have contributed to the decline of Chinook salmon, steelhead, and green sturgeon populations in the Central Valley. However, the single biggest cause has been the construction of massive dams and diversions on all major rivers (Moyle 2002; NOAA Fisheries 2005).

Other structures besides dams that block or delay migrating fish from accessing habitat include: road crossings, bridges, culverts, flood control channels, erosion control structures, canal and pipeline crossings, flow measurement weirs, pumping plants, borrow pits, and gravel mining pits (DWR, 2005; PSMFC, 2011).

In the Sacramento-San Joaquin system, dams have denied Chinook salmon access to more than half of the stream reaches they once used and to more than 80 percent of their historical holding and spawning habitat (Moyle 2002). Shasta and Keswick dams block winter-run Chinook salmon access to more than approximately 100 miles of historical habitat in the Little Sacramento River, Pit River-Fall River-Hat Creek, and McCloud River (Lindley et al. 2004).

Approximately 80 to 90 percent of spring-run Chinook spawning and rearing habitat has been lost due to water system developments in the Central Valley watersheds (DWR 2005). Large valley rim dams (e.g., Shasta and Oroville dams) and hydropower development projects have prevented spring-run Chinook salmon from accessing significant areas of upstream summer holding and spawning habitat (DWR 2005). NOAA Fisheries has identified several major dams that affect spring-run Chinook salmon migration, including: Englebright Dam, Oroville Dam, Keswick Dam, Shasta Dam, RBDD, and the Anderson Cottonwood Irrigation Diversion Dam[10] (NOAA Fisheries, 2009a).

Barriers to spawning habitat are a major anthropogenic threat to fall-run Chinook salmon (Stillwater 2007). Lindley et al. (2009) attributed the 2007 collapse of the fall-run population to a combination of unfavorable ocean conditions and anthropogenic effects such as the presence of large dams and levees, which block access to spawning and rearing habitat.

Lindley et al. (2006) estimated that approximately 80 percent of stream habitat that was historically available to anadromous Central Valley steelhead is now behind impassable dams, and that 38 percent of the populations identified have lost their entire habitat. In addition, NOAA Fisheries (2009a) highlighted steelhead passage issues at the following large dams: Friant Dam, La Grange Dam, Don Pedro Dam, Goodwin Dam, New Melones Dam, McSwain Dam, Crocker Huffman Dam, Camanche Dam, Pardee Dam, and Bellota Weir.

The principle threat to green sturgeon has been the loss of access to habitat for spawning and rearing, now upstream of impassable dams (NOAA Fisheries 2005). The presence of Keswick Dam currently blocks sturgeon passage to upstream sites (Adams et al. 2002; NOAA Fisheries2010b). The Red Bluff Diversion Dam gates have historically delayed migration, blocked access to 53 miles of upper river habitat with suitable water quality conditions for green sturgeon spawning and rearing from May 15th through September 15th of each year (NOAA Fisheries, 2009b). Early gate closures before May 15 have resulted in mortality of green sturgeon (NOAA Fisheries, 2009b). However, that impediment was

[10] The Anderson Cottonwood Irrigation District diversion dam was improved in 2001 with the installation of new fish ladders and fish screens around the diversion. However, NOAA Fisheries indicates that diversion dam operations could still impact Chinook salmon (NOAA Fisheries 2009b).

eliminated with the implementation of the Red Bluff Fish Passage Improvement Project, which was completed in 2012. As part of the project, a screened pumping plant was constructed that allows the RBDD gates to be permanently placed in the open position for free migration of salmon and sturgeon. Passage to 5 miles of spawning habitat downstream from Keswick Dam is also blocked by the Anderson Cottonwood Irrigation District Dam (installed April to November). The continued presence of green sturgeon adults below Oroville Dam suggests that sturgeon are trying to migrate to upstream spawning areas now blocked by the dam.

In addition to fish passage problems at large dams, Moyle et al. (2002, 2008) and NOAA Fisheries (2005, 2009b) identify other factors as contributing to the decline of Chinook salmon, steelhead, and green sturgeon populations:

- Lack of in-stream flow
- Fishing, both in the ocean and in streams
- Entrainment of juveniles in diversions
- Loss of floodplain and estuarine rearing habitat by diking and draining
- Predation
- Competition from hatchery reared juveniles
- Diseases, native and introduced
- Pollution and pesticides
- Unsuitable water temperatures
- Loss of riparian forests
- Siltation of spawning areas
- Effects of introduced fish, invertebrates, and plants
- Periods of drought
- Extreme flooding events
- Unusual ocean conditions
- Climate change effects

Although there are many factors that have contributed to the decline of salmonid and sturgeon populations in the Central Valley, this report focuses on fish passage technologies and solutions at large dams.

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Fish Passage Technologies

Many types of technologies are used to pass fish upstream or downstream at dams throughout the world. Some of these provide volitional passage which is fish passage made continuously without trap and transport (NMFS 2008). These types of passage facilities, such as fishways for upstream migrants and fish bypasses for downstream migrants, let the fish choose when to move past a dam by providing a constant hydraulic connection from the reservoir upstream of the dam to the river downstream of the dam. Non-volitional technologies rely on humans or machines to provide assistance in the passing of fish. Examples of these technologies are lifts, locks, and collection and transport. These technologies do not have a constant hydraulic connection, and may take hours for one load of fish to be moved.

NMFS generally prefers volitional passage, as opposed to collection and transport, for all fish passage facilities. This is mainly due to the risks associated with handling and transporting migrating salmonids, and the long term uncertainty of funding, maintenance, and operation of these types of programs. Further, collection and transport programs may not operate at the start and end of migration periods because there are only a few individual fish present. This practice is likely to have an adverse affect on salmon population diversity. In contrast, volitional passage facilities operate every day, year round. However, there may be locations where non-volitional passage, such as collection and transport, may be the best option for fish passage due to the height of the dam, possible temperature issues with a long fishway, or passage being needed past multiple dams (NMFS 2008).

In California, all of the large dams, such as Shasta or Oroville, were constructed without upstream or downstream fish passage. Instead, hatcheries were built to compensate for lost habitat for salmonid species. In addition, because the dams at major reservoirs that ring the Central Valley did not provide passage, many of the hydropower facilities located at higher elevations were not provided with fish passage either (CEC 2005). At smaller dams in California, upstream passage is provided almost exclusively through the use of fish ladders (Cada 1997 as cited in CEC 2005). Lifts, locks, and collection and transport operations are used only minimally within the state (CEC 2005).

This section provides a general overview of the fish passage technologies used at dams, regardless of size, and describes the uses and limitations of each type of passage technology.

Upstream Fish Passage Technologies

The main goal of upstream fish passage facilities is to attract migrants to a specified point in the river downstream of the structure and to induce them or make them move upstream through a waterway or by collecting and transporting them upstream (FAO 2001).

Two things should be considered when designing an upstream passage facility: the needed hydraulic characteristics of the facility and the fish species you of concern. Biological and hydraulic criteria for designing fish passage facilities vary with species and sizes of fish (Katopodis 1992).

According to Larinier (2000), there are several types of fish passage facilities that have been well developed for passage of anadromous species: fishways (ladders and nature-like channels), fish lifts and locks, and collection and transport facilities. Fish ladders have been used most often in North America and Europe. FERC (2004) reported that within the United States, lifts, locks, and Denil fish ladders are used most often in the Northeast, and pool type ladders are more common in the West/Northwest. Nature-like fishways such as roughened channels have also been used because they provide diverse hydraulic conditions, mimic natural channels, and blend in better with their surroundings. Each passage technology has strengths and weaknesses and may only be suitable for certain sites.

Fishways

In his book, Design of Fishways and Other Fish Facilities, Clay (1995) states:

> Fishways have a long history, with the earliest ones recorded almost 300 years ago in Europe. Undoubtedly, there was a realization of the need for fishways even before this, but in those earlier times, as one would expect, the problems involved in meeting this need were very poorly understood. Unfortunately, almost the same lack of understanding has persisted down to modern times, and we are now in the position of having to overtake, in a matter of years, the fish-passage problems created by a hundred years of industrial development. In many areas it is too late to apply our knowledge, because the populations of migratory fish have been completely destroyed, and the problems of restoring them in such cases are often insurmountable. There are, however, many migratory species of fish left in the rivers of the world, and our growing confidence in scientific research and management, coupled with the recognition of the need for preservation, cannot help but enable us to achieve a large measure of success in preserving and even increasing their numbers. The construction of adequate fishways is one of the means needed to achieve this end.

Fishways provide volitional fish passage, as they are constantly hydraulically connected. They can be divided into three main categories; pool-type, baffle-type, and nature-like. The design of fishways is primarily based on hydraulic criteria such as flow, velocity, turbulence, and drop height (DFG 2009). The behavior and swimming ability of the target species determines the hydraulic criteria used in the design. If juvenile fish will be passed, more stringent hydraulic criteria need to be used. Large water level differences between pools, excessive flow velocities and turbulence, large eddies, and velocities and depths which are too low can create barriers for fish. In addition, fish are sensitive to other environmental factors such as the level of dissolved oxygen, temperature, noise, light, and odor which can negatively affect migration. This applies particularly if the quality of the water feeding the fishway is different to that passing across the dam (Larinier 2000).

A fishway can be full channel width, partial width, or a bypass around a structure outside of the main channel. The full width fishway is advantageous in that fish have no problem finding the entrance to it and it can be constructed completely downstream of the barrier with the upper end of the fishway at the barrier. The partial width fishway can be on either side of the channel, or in the middle. To be effective, the entrance should be near the barrier, so the fishway may need to cut through the barrier and have its exit upstream, possibly complicating construction and the hydraulics of the fishway. The bypass fishway is isolated hydraulically from the channel and usually has the smallest project footprint. As with the partial width fishway, the entrance should be at the barrier and auxiliary water may be needed to provide the necessary attraction flow. The determination of the entrance location can be difficult because of varying hydraulics at the barrier during different flow regimes. One advantage of the bypass fishway is that, since it is isolated, most of the construction and maintenance can proceed in dry conditions outside of the channel (DFG 2009).

Please see DFG's Fish Passage Design and Implementation Chapter in their California Salmonid Stream Habitat Restoration Manual for more detailed information on fishways.

Pool-Type Fishways

Pool-type fishways, often called fish ladders, are a series of pools at consecutively higher elevations. Water flows over weirs, through orifices, or through slots to move from pool to pool. Fish must be able to easily overcome the water surface differential between pools by swimming or leaping. The water volume in the pool dissipates the water's energy before reaching the drop to the next downstream pool (DFG 2009).

The entrance configuration and attraction flow are important features of pool-type fishways. Attraction flow mimics the turbulence and water movement of the river and encourages adults to enter and ascend the ladder (Clay 1995). Improper flows can mean that fish cannot find the ladder entrance and migration is delayed. Flows in these types of fishways can vary from around one cfs to several hundred cfs and the slope from less than 5% to more than 20%, most frequently ranging from 10% to 12% (Larinier 2000).

Figure 11: Pool and Weir Fishway at the Feather River Fish Hatchery, California (CA Department of Water Resources)

Pool-type fishways are seldom used to overcome a maximum hydraulic head of more than 100 feet, although some have been used for higher applications. For example, the 2.84 mile long Pelton Fishway on the Deschutes River and the 1.7 mile long Faraday-North Fork Fishway on the Clackamas River, both overcome hydraulic heads of over 200 feet (see Case Studies). However, the Pelton fishway is not being used in its entirety to pass fish (Don Ratliff, Personal communication, October 7, 2010). Therefore, according to the Portland General Electric website (2011a), the Faraday-North Fork fishway is "the longest operating fish ladder in the world". The lowest 9 dams on the Columbia River and the 4 dams on the lower Snake River all have hydraulic heads of between 40 and 105 feet and multiple pool-type fishways.

The three major pool-type fishways are the pool and weir, pool and chute, and vertical slot.

Pool and Weir Fishways

Pool and weir fishways historically have been used most often for passage at lower dams. The fishway is an open channel, usually constructed with concrete, with pools that are separated by weirs (Figure 11). The weirs are typically horizontal, but can be sloped or have notches in them. Sometimes the fishway has one or more orifices in the weirs, which allow fish to swim from pool to pool instead of leaping over the weirs. The amount of flow, the geometric characteristics of the fishway, and the water surface differential between pools determine how water will behave as it flows down the fishway (DFG 2009).

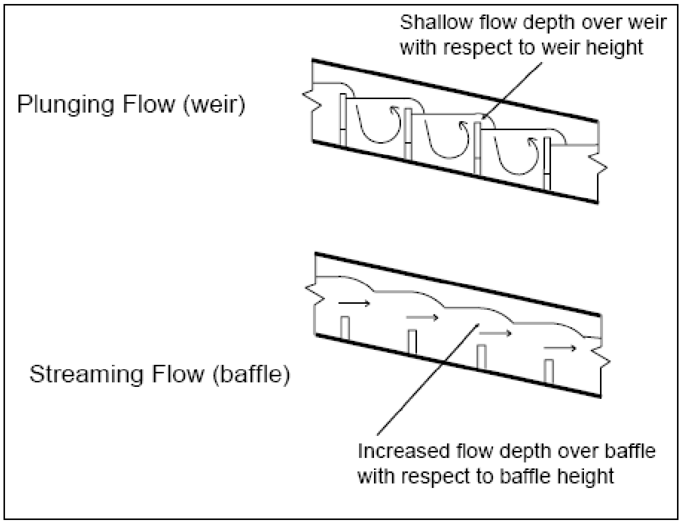


Figure 12: Plunging and Streaming Flow (DFG 2009)

The pools in the fishway offer resting areas for fish and ensure adequate energy dissipation of water (Larinier 2000). The normal flow regime in the fishway is a plunging circulation pattern. Water passing over the upstream weir plunges toward the fishway floor, moves downstream along the floor, then rises along the upstream face of the downstream weir and either drops over the weir or moves back upstream along the surface of the pool (Figure 12). As the flow in the fishway increases, the depth of water over the weirs increases and the flow transitions to a streaming flow regime. In this case, a continuous surface jet passes over the series of weir crests and skims along the surface of the pools, creating a circulation pattern opposite to that of the plunging regime (DFG 2009).

Dimensions of the pools of the fishway depend on the style of fishway, target species, scale of the river, and degree of flow control. Pools can be very small when dealing with smaller fish, but typically are in the range of four by six feet to eight by twelve feet. Typical pool depths for these ladders vary from three feet in streams and smaller rivers to eight feet or more in large rivers. In California, the maximum water surface differential between successive pools is one foot for adult anadromous salmonids and six inches for juvenile salmonids (DFG 2009).

Figure 13: Ice Harbor Fishway (Courtesy of U. S. Army Corps of Engineers)

Figure 14: Half Ice Harbor Fishway at Cougar Dam on the South Fork McKenzie River (CA Dept. of Water Resources)

Debris can be a problem in pool and weir fishways, as it can catch on weirs, notches, or orifices. In addition, sediment accumulation can affect the performance of the fishway by filling in pools and thus reducing their energy dissipation capability.

A specific type of pool and weir fishway is the Ice Harbor fishway (Figure 13). Each weir of the Ice

Harbor fishway has a non-overflow center section with flow stabilizers. The fishway also has orifices, is built on a 10% slope, and is recommended for moderate to large applications with good flow control. For lesser flows, the Ice Harbor fishway can be cut in half along the centerline to produce the Half Ice Harbor fishway (Figure 14). Half Ice Harbor fishways have recently been built at the 85 foot high River Mill Dam on the Clackamas River in Oregon (Bartlett and Cramer 2006) and at the adult collection facility at Cougar Dam on the South Fork McKenzie River.

Pool and Chute Fishways

The pool and chute fishway (Figure 15) is similar to the pool and weir fishway in that water flows over a weir from pool to pool. The difference is that a pool and chute fishway has a center notch and sloping weirs that extend to the fishway walls. At low flows, the fishway behaves like a pool and weir fishway, with water only passing through the center notch and spilling over the horizontal weir. At moderate to high flows, parts of the fishway operate in both plunging and streaming flow regimes simultaneously (DFG 2009). Water spreads across the fishway and up the sloping weirs, creating plunging flow at the flow margins. Under this condition, high velocity streaming flow exists in the center of the fishway. The fishway should be designed so that the high fish passage design flow doesn't quite cover the entire width of the sloping weirs (at least 2 feet from the wall is recommended). Orifices can be included at the floor to help stabilize the flow and provide a submerged swimming option for fish (Powers 2001).

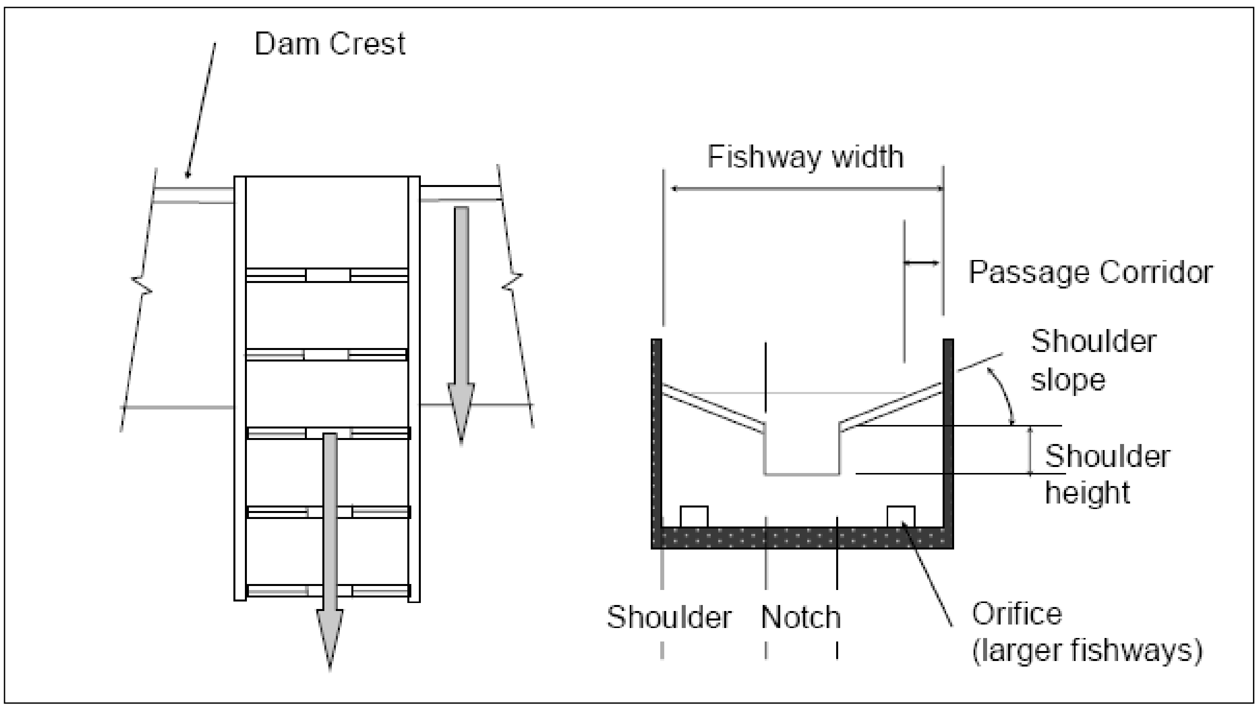


Figure 15: Pool and Chute Fishway (DFG 2009)

Figure 16: Pool and Chute Fishway at Willow Slough Weir in the Sutter Bypass - Northern California (CA Department of Water Resources)

The pool and chute fishway has many benefits. For smaller applications, all of the flow can be contained in the fishway and the fishway creates a strong jet, making it very attractive to migrants. Also, large fishway flows can scour sediment and debris from the fishway, reducing maintenance. In addition, several passage routes are available to fish moving upstream and the size of the pools can be smaller than a pool and weir fishway for the same range of flows (DFG 2009).

The pool and chute fishway also has some disadvantages. The fishway must be aligned in a straight line without bends, since it has high velocities down the center at moderate to high flows. The high velocities can cause erosion downstream of the fishway if the channel is narrow or if the fishway is aligned towards a bank. The hydraulics and biological effectiveness of the fishway has not been evaluated extensively (DFG 2009). Therefore, the California Department of Fish and Game (2009) recommends, “no more than five or six feet of head differential should be taken through a pool-and-chute because of the uncertainties of stability with the high energy in the fishway and the limited hydraulic verification done”.

The pools for the pool and chute fishway are typically wider and shorter than a pool and weir fishway. For the Willow Slough Weir fishway (Figure 16), the pools are 20 feet wide and 7 to 8 feet long. As with the pool and weir fishway, the maximum water surface differential between pools should be one foot or less for anadromous adult salmonids and six inches or less for juveniles. The maximum slope for the fishway should be 10% (DFG 2009).

Vertical Slot Fishways

Vertical slot fishways do not have overflow weirs as do the previous pool-type fishways. Hydraulic control and fish passage are provided by full-depth slots between the pools (Figure 17).

Figure 17: Vertical Slot Fishway at Coleman National Fish Hatchery (CA Department of Water Resources)

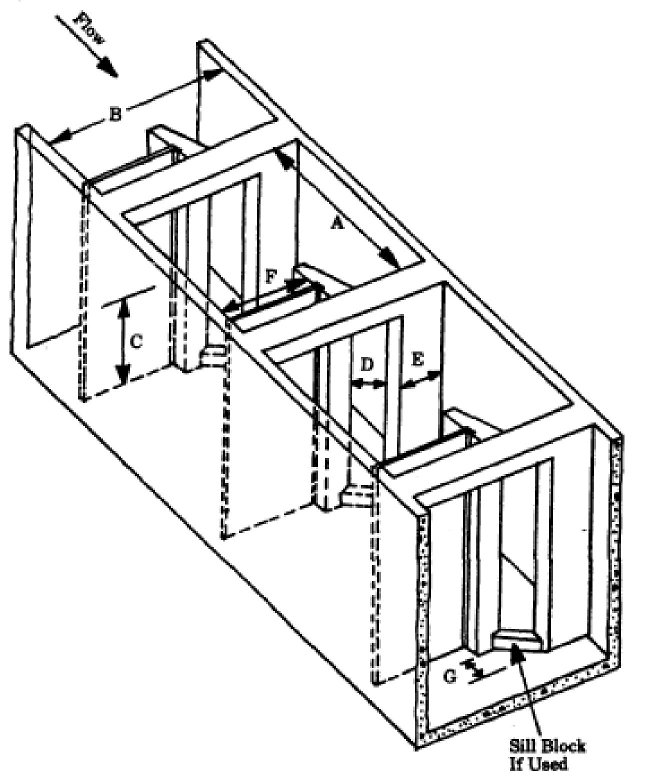
A benefit of the vertical slot design is that it is self-regulating and operates throughout the entire range of design flows without adjustment. That means that the water surface elevation difference between the tailrace and forebay will be divided equally between all of the fishway slots. The fishway automatically compensates for any change in forebay or tailrace water surface elevation. The vertical slot fishway's full depth slots also allow fish passage at any depth (DFG 2009).

Energy is dissipated by the water jet through the slot mixing with the water in each pool (Katopodis 1992). Pool depths increase as flows increase, creating additional pool volume and thereby maintaining the needed energy dissipation (DFG 2009).

Since fish must swim the entire length of the fishway, the vertical slot fishway is not the best choice for species that need overflow weirs for passage. For instance, juvenile salmonids will have more passage success leaping over a weir than trying to burst through a slot with a high velocity flow. The vertical slot fishway gives them no opportunity to leap (Katopodis 1992).

It is critical to the stability of flow in the vertical slot fishway that the design uses the dimensions described by Bell (1991), unless it is known, from studies or experience, that other configurations will work (Figure 18). Changes from the standard dimensions can cause unstable flow conditions and water surging in the fishway. Shallow depths can cause hydraulic problems in the fishway, as the water jet through the slot shoots across the pool and to the next slot. Sills at the bottom of the slot should be added if the pool upstream of the slot is to be operated at depths less than 5 feet (DFG 2009).

A vertical slot fishway is being designed for 96 foot high Trailbridge Dam on the McKenzie River in Oregon (Andrew Talabere, Personal Communication, November 2, 2011).



A	Pool Length	6'	8'	10'
B	Pool Width	4'	6'	8'
C	Water depth (Min)	2'	3'	3'
D	Slot Width	.5*	.75*	1.0*
E	Wing Baffle Length	9"	1'-3¾"	1'-3¾"
F	Wing Baffle Distance	2'	3'-1"	3'-7"
G	Displacement of Baffle	4'	5'-½"	5'-½"
	Discharge Per Foot of Depth Above Block in CFS	3.2	4.8	6.4
	Drop Per Pool	1'	1'	1'

*Sill Block in Place

Figure 18: Vertical Slot Fishway (Bell 1990)

Baffle-Type Fishways

The two common styles of baffle-type fishways are the Denil and Alaska Steeppass (Figure 19), which are fabricated flumes constructed out of aluminum, steel, or wood with angled baffles. The baffles create roughness which controls the velocity in the fishway, even at high slopes (DFG 2009). They are narrow fishways, typically less than 5 feet in width, which in combination with the baffles make them very susceptible to debris blockages. Both types require a consistent headwater pool elevation upstream to be effective, as variations of more than a foot will create passage difficulties (WDFW 2000b).

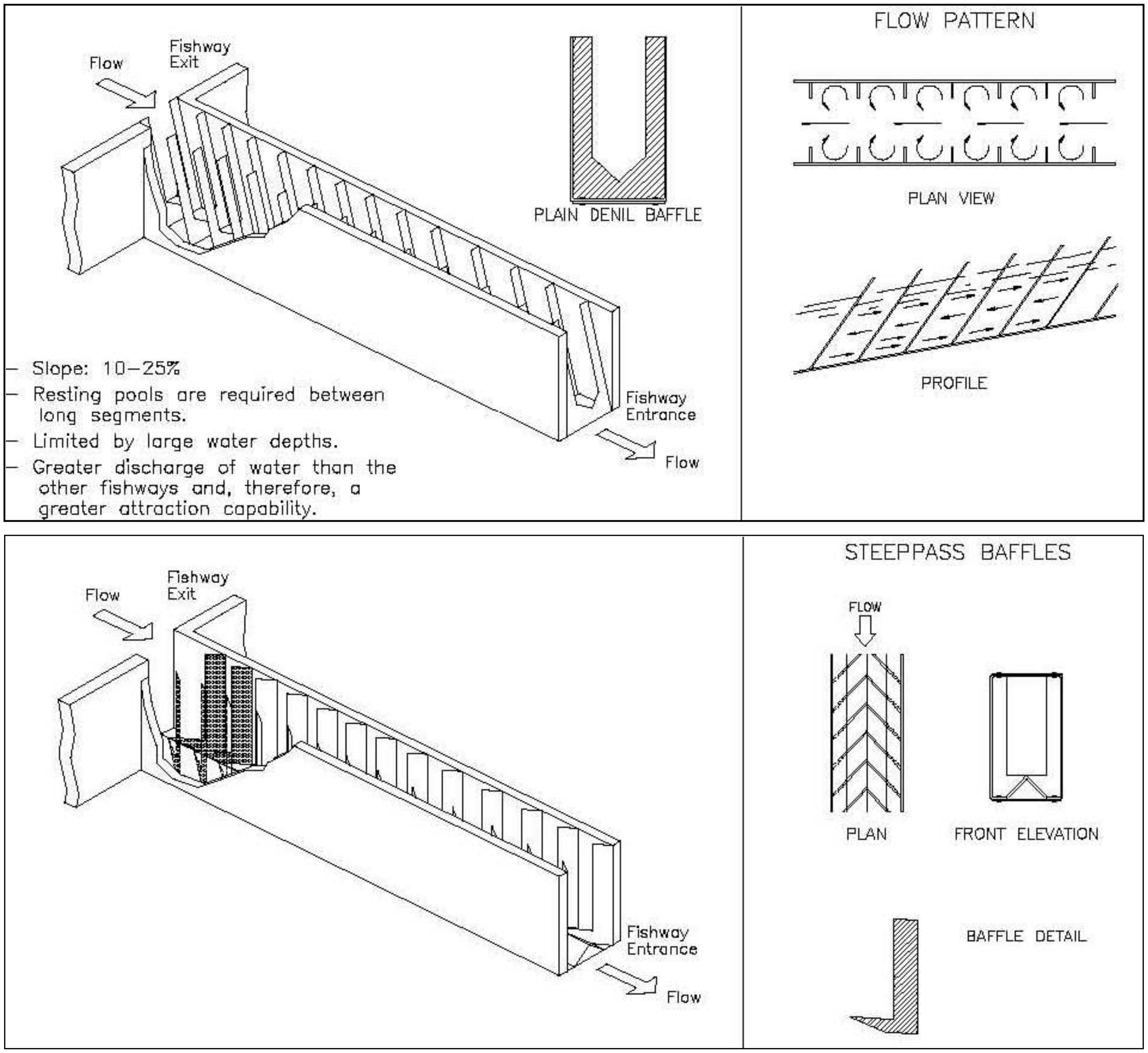


Figure 19: Denil (top) and Alaska Steeppass Fishways (Katopodis 1992)

For the Denil, a slope of 17% is recommended, but slopes of up to 25% have been used successfully. The Alaska Steeppass can be set steeper, up to 33%, with a normal slope of 25% (WDFW 2000b). Since fish must pass through these fishways without stopping, longer fishways may exceed the limits of their endurance. Therefore resting pools should be constructed between fishway sections (Larinier 2000). Both types of fishways have been used throughout the world for passage at smaller barriers, but are not the best choice of fishway for settings where debris, sediment, and weak-swimming fish are to be passed. They are currently used in California at trapping and evaluation facilities and for temporary fish passage during in-water construction activities (DFG 2009).

Nature-Like Fishways

The nature-like fishway is designed to mimic a natural channel and provide suitable conditions for passage over a range of flows for fish and other aquatic organisms (Katopodis 2001). The fishway is designed to recreate pools, riffles, steps, and/or cascades using natural materials. This type of fishway is usually used at low-head barriers and can be a full channel width (Figure 20), partial channel width (Figure 21), or bypass type design (Figure 22). Nature-like fishways are constructed mainly with rock, with the smaller particles, such as sand and gravel, filling the voids between the larger ones (Katopodis et al 2001). In California, the Department of Fish and Game calls these fishways roughened channels, describing them as, “constructed channel reaches stabilized with an immobile framework of large rock mixed with smaller material.”

Figure 20: Full width nature-like (rock ramp) fishway (Photo by Uli Dumont in Wildman et al 2002)

Figure 21: Partial width nature-like (rock ramp) fishway (Photo by Uli Dumont in Wildman et al 2002)

Gebler (1998) summarizes the advantages of nature-like fishways as follows:

- Suitable for a variety of aquatic species
- Enriched habitat for aquatic species that prefer faster moving water
- Low construction, operation, and maintenance costs compared to traditional fish passage technologies
- Can handle a wide range of flows
- Allows for movement of sediment through the fishway
- Flexible construction allows for modifications
- Allows for easy integration into the landscape
- Greater aesthetic value

Figure 22: Nature-like bypass channel (Photo courtesy of Rolf-Jurgen Gebler)

Unlike traditional (concrete) fishways, nature-like designs have not been developed using extensive hydraulic research (EPRI 2002). Most nature-like fishways have been designed intuitively to be heterogeneous and meet the requirements for fish passage at a specific site. The design process is based on the fish community present and the characteristics of the natural channels in which these fish are found (Parasiewicz et al 1998). Successful projects have demonstrated that nature-like fishways provide fish passage and aquatic habitat, and are often inexpensive to construct and reasonable to maintain (Wildman et al 2002).

Many nature-like fishways have been constructed throughout the world and this type of fishway has come to the forefront as a recommended design for passage at low-head structures in California. Since they are fairly new to California and the design methods have not been extensively tested, monitoring of projects is especially important (DFG 2009).

As for the applicability of nature-like fishways, Wildman et al (2002) documented many case studies, most of which have hydraulic heads of less than 15 feet. However, some of the bypass channel case studies have greater hydraulic heads, with one passing fish around a 40 foot high dam. One project currently being constructed is a 900 meter long, 50 meter wide (3,000 foot long by 160 foot wide) nature-like bypass channel on the Rhine River in Rheinfelden, Germany (Figures 23 and 24). This bypass overcomes the 9.1 meter (30 foot) hydraulic head created by the Rheinfelden Power Station and associated dam. Flow in the bypass will be up to 35 cms (1235 cfs) (Gebler 2011).

Figure 23: Aerial view of the nature-like bypass channel at the Rheinfelden Power Station on the Rhine River (Courtesy of Rolf-Jurgen Gebler)

Figure 24: Nature-like bypass channel at the Rheinfelden Power Station on the Rhine River (Courtesy of Rolf-Jurgen Gebler)

Common configurations of nature-like fishways include rock ramps spanning a part or the full width of the channel, step-pool or cascade-pool sequences, and bypass channels around dams or drop structures. Short segments of the fishways may be steeper, but overall slopes commonly range between 3% and 5%, which are within the range of slopes that salmonids normally inhabit in natural waterways (DFG 2009).

The following sections are taken directly from the California Department of Fish and Game's Fish Passage Design and Implementation Chapter in their California Salmonid Stream Habitat Restoration Manual (DFG 2009). The sections describe bedform morphology for different roughened channel types, including rock ramps, chutes and pools, step-pools, and cascade and pools.

> In general, when a roughened channel extends in length for roughly five or more channel widths, it is recommended that a large pool be added to break up the reach and aid in dissipating energy. Each reach of steep channel and pool combination is referred to as one sequence. The following table lists each channel type and their recommended slope ranges. There is not always a clear distinction among these bedforms in nature.

Bedform	Overall Roughened Channel Slope	Recommended Maximum Elevation Drop Across Roughened Channel
Rock Ramps	$\leq$4.0%	5 feet[1]
Chutes and Pools	$\leq$4.0%	2 feet per Sequence
Step-Pools	3.0-5%	5 feet per Sequence[2]
Cascade and Pool	4.0-6.5%	5 feet per Sequence

Recommended range of overall design slopes and maximum elevation drops for various roughened channel bedforms (DFG 2009)

[1] Larger drops across the roughened channel require breaking up the reach with large pools.

[2] A step-pool sequence may include multiple steps; four or five steps per sequence are common.

Much of the design guidance for roughened channels is based on the characteristics of natural channels. There is some risk in using a natural channel as a template for design of a channel that is intended to be stable, if not rigid. Natural channels have evolved over decades if not centuries and have been formed by a history of flow events likely including some extreme flows. Even the best design and construction practices cannot duplicate the structure and hydraulic sorting and particle [sic] done in nature. Consider the slope, spacing, and rock sizing describe [sic] as natural limits. Mitigate any risk and uncertainty by designing conservatively relative to those limits.

Rock Ramps

Rock ramps are continuous roughened channels constructed at a constant slope with no large structural bedforms (e.g., steps, pools). Rather, random large rocks in the engineered streambed material create hydraulic roughness and diversity (Figure 25).

Figure 25: Rock ramp roughened channel at the Budiselich Flashboard Dam site in the Stockton Diverting Canal, Calaveras River System (CA Dept. of Water Resources)

Rock ramps are often limited to slopes less than 4% and are best for overcoming elevation differences of 5 feet or less. Higher and longer rock ramps may be less stable due to the potential for increasing water velocities in the downstream direction. Additionally, the risk of creating an exhaustion barrier to fish increases as the ramp length increases. To overcome larger elevation differences, rock ramps can be interspersed with large pools to form a sequence of chutes and pools or small pools can be scattered within rock ramps.

Rock ramps and chutes rely on the swimming, rather than leaping, abilities of the fish, making them better suited for passage of fish species and life stages that have poor or no leaping abilities. However, to achieve adequate water depth for fish passage, a sufficient amount of flow is required, which limits their application. In streams with very low base-flows, rock ramps and chutes may not be able to provide adequate water depth for fish passage during low flows. This concern is increased with increasing slope, channel width, and the likelihood of significant subsurface flow.

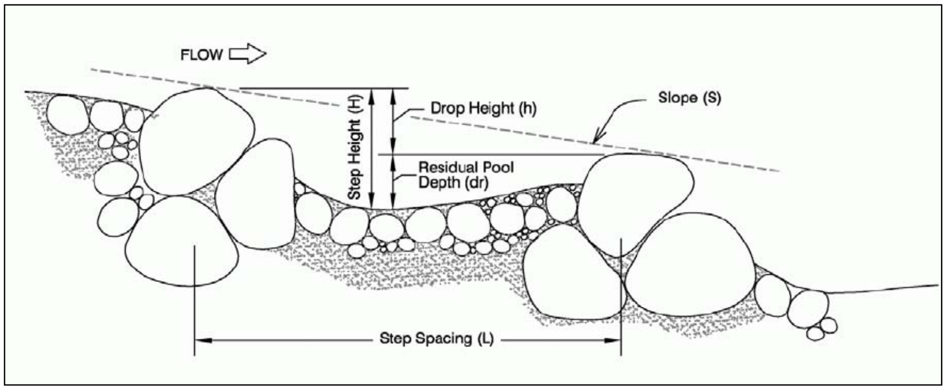
Chutes and Pools

A chute and pool channel consists of a short rock ramp subunit followed by an armored pool subunit. The bed structure of this repeating sequence dissipates energy through a combination of hydraulic roughness across the chute and the volume of the pool below the chute. Chutes and pools are recommended in lieu of rock ramps when the roughened channel is long or when the unit discharge (flow in channel divided by active channel width) is high. The recommended maximum overall slope for rock chutes and pools is 4% for small and moderate-sized streams, with the slope of the chutes greater than 4% and no slope across the pools. The drop across a ramp/pool sequence is typically limited to two feet to adequately dissipate the flow's energy.

Step-Pools

A roughened channel can be designed to simulate a step-pool channel. Natural step-pool channels typically occur at channel slopes between 3.0% and 6.5%, but can be found in lower and higher sloping channels (Montgomery and Buffington 1997). Steps are ribs across the channel composed of boulders, logs, or bedrock. Water plunges over each step and into pools formed between steps. This bedform dissipates the stream's energy as water flows over the step and plunges into the receiving pool. The pools are armored and resistant to scour and erosion. Step-pool channels are generally highly confined and the stream banks are relatively rough and resistant to scour.

The step-pool channel unit can be built at slopes between 3% and 5%. Because water often accelerates as it flows down this type of channel, the recommended maximum overall drop across a series of steps is 5 feet. If larger drops must be overcome, it is necessary to breakup steep step-pool reaches with large pools to dissipate accumulating energy.



Dimensions used to describe a step-pool channel in profile

Cascade and Pools

Natural cascade channels are steep channels characterized by large roughness elements relative to the water depth and without repeating bedforms (Montgomery and Buffington 1997). They are most likely to have natural slopes greater than 6.5%, but have been observed in channels with slopes as low as 4.5%. Cascade channels contain small, partially channel-spanning pools spaced less than one channel width apart. The channel bottom is relatively flat. Large keystone rocks that are essentially immobile are found randomly throughout the active channel, with many of them located near the center of the channel. The size of the keystone rocks are close to or exceed the channel's bankfull depth. Their large size relative to the channel creates flow constrictions and retains smaller boulders and large cobbles to form complex steps at lower flows.

A cascade, as described above, can be used as bedforms for roughened channels. This type of bedform is best suited for profile control in stream reaches that are already steep (> 3%), and have relatively coarse bed material and confining banks. Given the steep slope and tendency for water to accelerate as it flows down a cascade, larger pools must be placed between short cascades to dissipate excess energy and provide holding areas for fish. To maintain suitable fish passage conditions, the cascades should not have a slope greater than 8% and the overall slope of the cascade and pool should not exceed 6.5%.

Constructed cascades are only suitable for relatively straight channel reaches that are highly confined, with floodplains that are small or nonexistent.

Unlike the channel spanning water surface drops created in a step-pool channel, the rocks in a cascade and pool roughened channel should create a complex series of smaller drops that effectively dissipate energy and provide fish with numerous pathways to swim upstream. During design and construction, care should be given to avoid creating situations where the drop criterion for fish passage is exceeded.

Fish Lifts and Locks

Fish lifts and locks are generally used for sites where vertical passage heights are excessive or for passing species that do not readily use fish ladders. They have the capability of moving fish vertically over high dams as well as reducing the physical demands on fish (California Energy Commission 2005). In addition, space requirements, construction costs, and flow requirements are usually less than traditional fishways for high head dams (Larinier 2002, FAO 2002).

Fish lifts move fish over a barrier by mechanical means. Fish locks are devices that raise fish over dams, similar to the way that boats are raised in a navigation lock.

Both lifts and locks have a much shorter history than fishways. The time of initial building of fish lifts and locks occurred in the 1920s, coinciding with the building of higher dams (Clay 1995). Lower Baker Dam (285 feet high) in Washington State was completed in 1927 and included an 800 foot long cableway fish lift to transport collected fish in small steel tanks to the top of the dam. In reference to this cableway, Clay (1995) states that, "this contrivance was hailed at the time as the answer to the problem of passing fish over all high dams." But in the late 1950s, the combination of the construction of Upper Baker Dam (312 feet high), the deterioration of the upstream passage facilities, and the inability of the facilities to handle the large numbers of upstream migrants caused the abandonment of the facilities and a decision to move to a trap and truck system.

In the late 1930s and early 1940s, fish lifts were developed for fish passage at high dams in the United States and Canada (Clay 1995). Fish lock development accelerated in Europe in the 1950s. One of the first installations was a Borland type lock at the Leixlip development on the River Liffey near Dublin, Ireland. Since then, more than a dozen Borland locks have been built in Ireland and Scotland, passing fish over dams up to 200 feet in height (Clay 1995).

Fish Lifts

A fish lift is a mechanical system that first traps the migrating fish in a hopper of water located at the base of an obstruction, and then raises and empties it into the upstream reservoir (Travade and Larinier 2002). There are two main types of fish lifts. The first type, designed for salmonids, attracts fish into a hopper (tank, trough) which has a v-shaped entrance (Figure 26). Once the hopper is loaded with fish, it is then lifted to the top of the dam and dumped into the dam forebay. The second type is for dams where large numbers (hundreds of thousands) of fish need passage. A large pool is used to hold the fish, which are then loaded into the lift using a mechanical crowder (Figure 27) (Larinier 1998). Like other fish passage systems, the efficiency of the fish lifts depends on their ability to attract fish into the collection chamber and lifting mechanism.

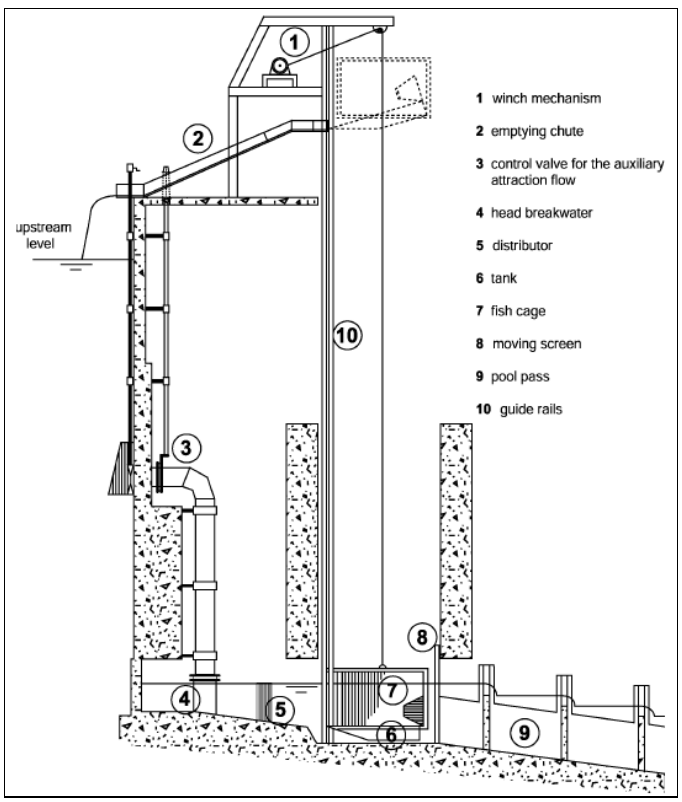


Figure 26: A Typical Fish Lift for Salmonids (Travade and Larinier 2002)

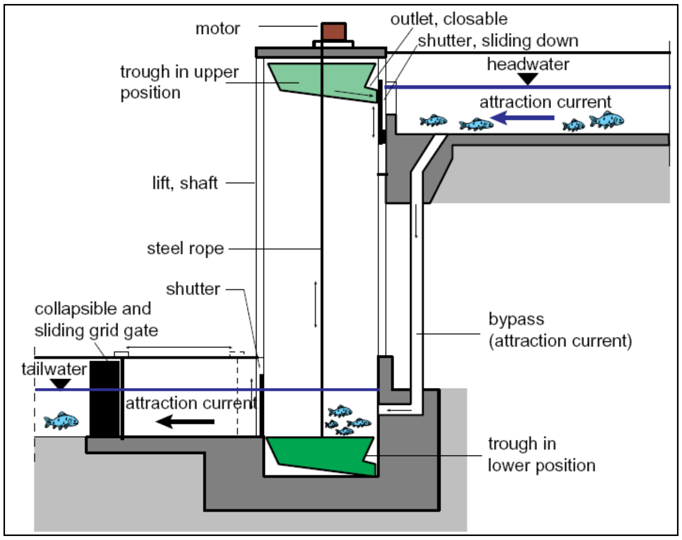


Figure 27: A Typical Fish Lift for Large Numbers of Fish (FAO 2002)

In North America, fish lifts (elevators) have been preferably used over fish locks to pass fish over high dams (Clay 1995). A great advantage of this type of technology is that it can be used at high head sites where traditional fishways would be very expensive (OTA 1995). Other advantages lie in the construction cost, which is practically independent of the height of the dam, their small overall footprint, and their low sensitivity to variations in forebay water level. They are also considered to be more efficient than traditional fishways for some fish species, such as shad (Larinier 1998).

The main disadvantage is the greater cost of operation and maintenance, as a fish lift is comprised of complex mechanical equipment with many moving parts and also metal parts that are partially or fully submerged in water. Breakdowns or periods of malfunction may occur frequently and/or last a long time. Fish lifts need regular inspection, upkeep of mechanical and electronic parts (hoists, sluices, screens, and machinery), and cleaning of screens (Travade and Larinier 2002). Another disadvantage is the intermittent operation of a fish lift, and its potential to delay fish at the base of the project (OTA 1995).

Fish Locks

The Irish engineer J. H. T. Borland developed the first fish lock as a scale model in around 1949. The design was then constructed at Leixlip Dam, and numerous locks of the Borland type (Figure 28) were subsequently built by the North of Scotland Hydro-Electric Board (Travade and Larinier 2002).

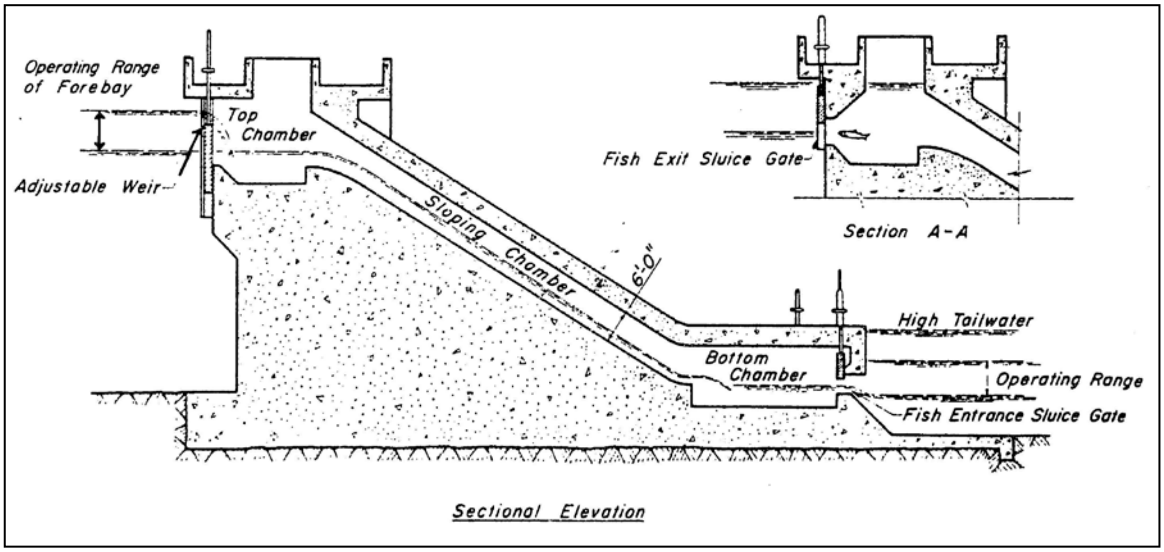


Figure 28: A typical Borland fish lock (Clay 1995)

In general, a fish lock attracts fish into the bottom of a vertical (Figure 29) or inclined chamber and then fills the chamber with water to the level of the dam reservoir. As the chamber fills, the fish follow the rising water level and then leave the lock by swimming into the reservoir (Clay 1995, Larinier 2000).

The operating cycle can be summarized as follows (Travade and Larinier 2002):

Attraction phase: The downstream sluice gate is open and the upstream sluice gate controls the flow into the fishway. Water flows into the pool formed by the upper chamber, then through the central conduit of the chamber towards the lower holding chamber, and finally out of the holding chamber into the tailwater of the dam. The flow attracts the fish into the lower holding chamber.

Filling and exit phase: After an attraction period lasting for a specified period of time, the downstream sluice gate closes and the lock fills up with water. The fish follow the surface of the water in the central conduit, rising and reaching the upstream pool when the lock is full. Fish are encouraged to exit by the attraction flow created when a bypass is opened in the lower chamber and the upstream sluice gate is partially lowered.

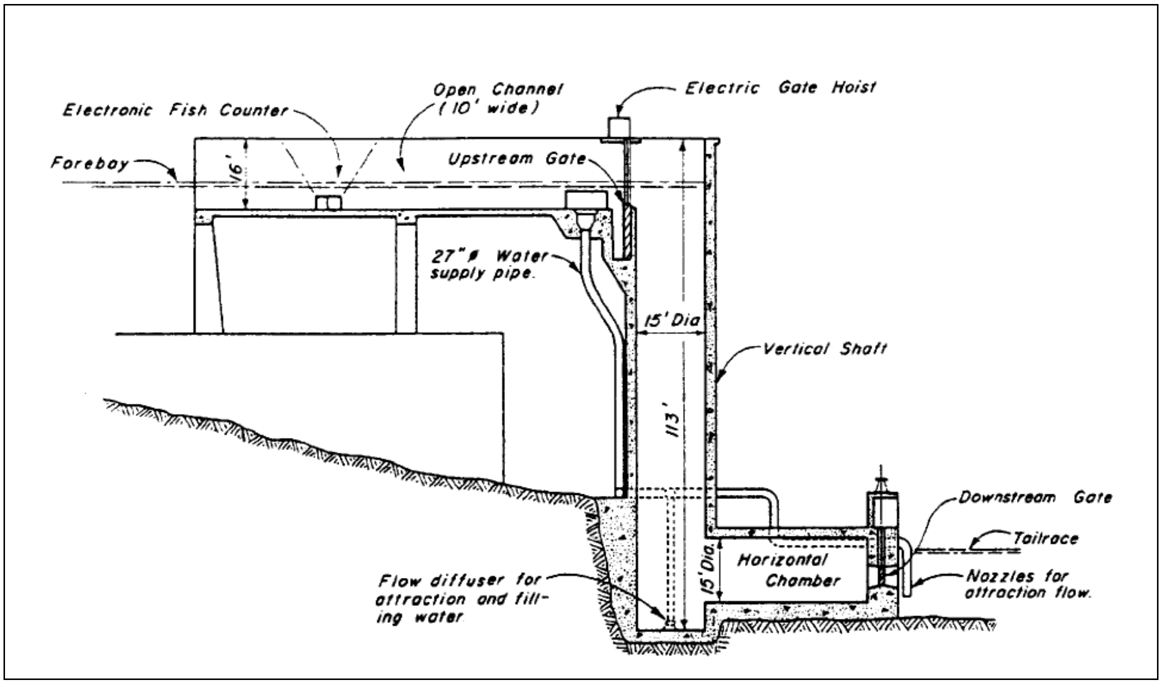


Figure 29: The vertical chamber fish lock at Ardnachrusha Dam in Ireland (Clay 1995)

Emptying phase: After a specified period of time, the upstream sluice is closed. The lock is gradually emptied by means of the still open bypass. When the chamber is almost empty and the head on the downstream sluice is low enough, the downstream sluice is re-opened. Emptying the lock by means of the bypass prevents high velocities occurring at the entrance to the lock, which might repel any fish that are in the vicinity of the entrance.

The duration of a cycle generally takes between 1 and 4 hours.

Borland locks are typically used at dams greater than 30 feet in height. At dams lower than 30 feet, a pool-type fishway is considered to be more effective and economical. One of the highest lock installations in the world is the Borland lock at 100 foot high Salto Grande Dam in South America. Another high and unique installation is the four Borland locks at 200 foot high Orrin Dam in Scotland. Multiple locks were needed because of the 70 foot fluctuation in water surface elevation (Clay 1995).

Locks built at dams on the Columbia River (Bonneville, The Dalles, McNary) and at other locations in the USA were abandoned in favor of pool-type fishways. Likewise, most locks in France are considered to be unsuccessful and some have been replaced by pool-type fishways. In some cases, mechanical crowders and followers have been installed to force fish into and up the lock chamber (Larinier 2000).

Like other fish passage technologies, the efficiency of the lock depends on the ability to attract fish. The entrance must be in a good location relative to the powerhouse tailrace and/or spillway. In addition, auxiliary water may be needed to enhance the attraction capability of the lock entrance (Travade and Larinier 2002).

The main disadvantage of fish locks is their limited capacity in terms of the number of fish that can be handled compared to that of a pool-type fishway. This is due to the discontinuous nature of their operation and the limited volume of the lower chamber. Since no significant flow is available to attract fish during the filling and exit phase, any fish arriving at the lock during this phase may leave the entrance area before the cycle returns to the attraction phase. Fish that do enter the downstream chamber during the attraction phase may also leave before the attraction phase ends and the filling of the lock begins (Travade and Larinier 2002).

In 2010, a 7 foot diameter fish lock was constructed on the Baker River in Washington to raise fish 60 feet to a fish facility on the river bank. From there, fish are sorted and loading onto trucks for transport to the upper watershed (PSE 2010).

Navigation Locks

The passage of migratory fish through navigation locks is usually accidental. Fish are generally not attracted to navigation locks because the locks are located in relatively calm areas of the river to enable boats to maneuver. At Bonneville dam on the Columbia River, studies have determined that less than 1.5 % of migrating fish use the navigation lock (Travade and Larinier 2002).

Nevertheless, studies have shown that navigation locks may be useful as a back-up fish passage facility or a viable alternative to the construction of a new fish passage facility at existing sites, providing that the navigation locks’ operation is modified to enhance fish passage. However, the need to operate the locks to pass boats will generally keep these locks from being efficient fish passage facilities, because the operational methods used for passing boats are often incompatible with those used for passing fish (Larinier 2000).

Collection and Transport

Collection and transport operations have been used successfully for moving adults upstream of long reservoirs or multiple reservoirs. This technology has been used for interim passage until construction of other passage technologies, such as ladders or lifts, is completed (CEC 2005). Collection and transport has also been used as a long-term fish passage measure at high head dams where the construction of a traditional fishway would be difficult, or where a series of dams intercept a reach void of valuable spawning habitat (Larinier 2000). Other reasons include a lower initial cost compared to constructing fishways, locks, or lifts and the concern that these methods may not be successful, especially at high head dams. At high head dams, collecting and transporting adult migrants may be the only feasible passage method (CEC 2005).

The success of a collection and transport operation depends mainly on the efficiency of collecting and handling fish. Separation of fish may be required to prevent the transport of non-target species. A potential benefit of this type of system is that it needs much less flow than pool-type ladders, which may make it the most feasible fish passage option for low-flow periods in California (California Energy Commission 2005).

Figure 30: Collection and transport facility at Keswick Dam in California

However, this method of fish passage can be controversial and there are concerns that handling and transporting migrating fish will have negative effects on their health and behavior. Potential adverse impacts on these fish include migration delay, interruption of the homing instinct, disorientation, disease, and mortality (OTA 1995).

In California, collection and transport operations have been used at Keswick Dam from 1943 to the present day (Krisweb 2011). In the Pacific Northwest, most projects at high head dams (greater than 100 feet) are or will be using the collection and transport method to move adult migrating salmonids upstream of a dam or multiple dams. Examples include the Baker River, Cowlitz River, Lewis River, Pelton-Round Butte, Cougar, Cle Elum, and Cushman Projects (see the Case Studies section for detailed descriptions of many of these projects).

Figure 31: Adult fish trap and lock on the Baker River, Washington (Courtesy of Puget Sound Energy)

The general concept of the collection and transport system is to block the passage of upstream migrating fish, attract them into a fishway or holding pool, trap them and sort them, and load them into a truck (typically) for transport upstream. The collection and transport system can be used in conjunction with a fish hatchery as well.At dams where developing a suitable entrance would be extremely expensive or physically impossible to build, such as in steep canyons, a barrier can be built downstream which will guide the fish to the entrance (Larinier 2000). The Cowlitz River and Baker River Projects are examples of two projects that use a downstream barrier weir to aid in the collecting of upstream migrants.

Several previously mentioned technologies, such as fishways, fish lifts, and fish locks, can be used to raise the fish up to a fish collection facility. At Keswick Dam, fish ascend a fishway to get to a holding pool, and then enter a fish lift that raises them up to the transport area (Figure 30). At the Cowlitz River Project, fish move up a series of fish ladders to get to the Cowlitz Salmon Hatchery. At the hatchery, fish are trapped and sorted by species and destination. As mentioned in the fish lock section, the Baker River Project uses a lock (Figure 31) to raise fish up to a fish facility for processing and loading onto trucks (PSE 2010). At Cougar Dam, fish climb a fish ladder to get to a collection facility for transport to the upper watershed (Figure 32).

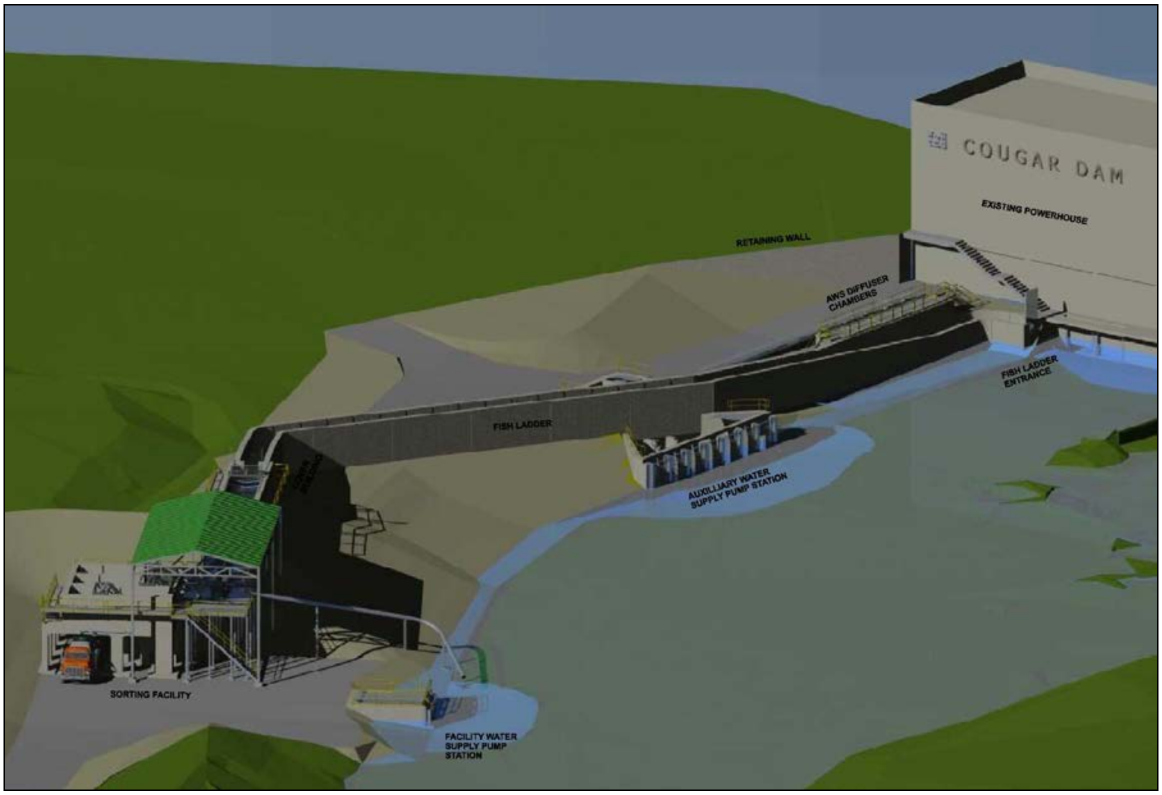


Figure 32: Adult fish collection facility at Cougar Dam in Oregon (Courtesy of USACE)

Downstream Fish Passage Technologies

In the early stages of dam development, engineers and fisheries biologists were preoccupied with providing fish passage facilities for upstream migrants. Turbine and spillway passage was not considered to be a main cause of damage to downstream migrants. Experience has shown that turbine and spillway passage can cause damage to downstream migrants and are major factors affecting these fish (Larinier 2000).

Since early fish passage efforts focused on upstream passage, downstream fish passage technologies are much less advanced and are the areas most in need of research. In addition, the development of effective facilities for downstream fish passage is more difficult and complex. Downstream migration issues have only recently come to the forefront (Larinier 2000).

For juvenile fish migrating downstream, dams and reservoirs present a complex set of hazards. In the reservoirs where the water is deep and slow moving, these fish move slower than they do in a typical riverine environment, causing migration delays. In addition, juvenile fish can be exposed to reservoir dwelling fish predators for a significant period of time. At the dam, turbines and spillways can cause injury or death to fish. After juveniles pass the dam, turbulence below the dam increases exposure of juvenile salmon to predatory birds (USACE 2002).

When considering downstream fish passage at hydropower facilities, one must have three distinct goals: 1) to prevent fish from entering into turbine intakes; 2) to allow fish to move safely downstream past the facility; and 3) to move fish, in a timely and safe manner, through the project reservoir. The first two are applicable to all hydropower facilities, but the third generally applies only to dams with larger reservoirs. Compared to upstream passage, there are generally more options available for downstream passage, but no downstream passage method is appropriate for all situations (CEC 2005).

Typically downstream migrants can pass a dam by three methods: turbines, spillways, or bypass systems (USACE 2002). Juvenile migrants can also pass dams by using the fishways or navigation locks, but since the percentage of fish using these methods is very small, they will not be discussed in this report.

Turbines

Dam powerhouses contain large generators for producing electricity. Water stored in the reservoir passes through intakes and penstocks to reach the turbines in the powerhouse (Figure 33). As the turbines turn, the connected generators produce electricity. The turbines can turn at a rate of anywhere from 50 to 600 revolutions per minute (USACE 2011c).

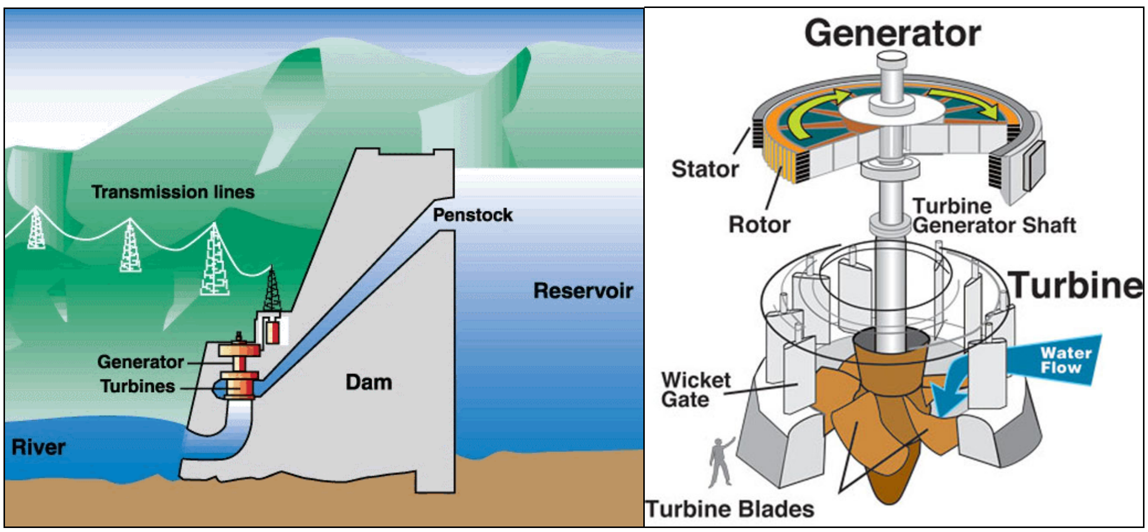


Figure 33: Hydropower Generation Diagrams (USACE)

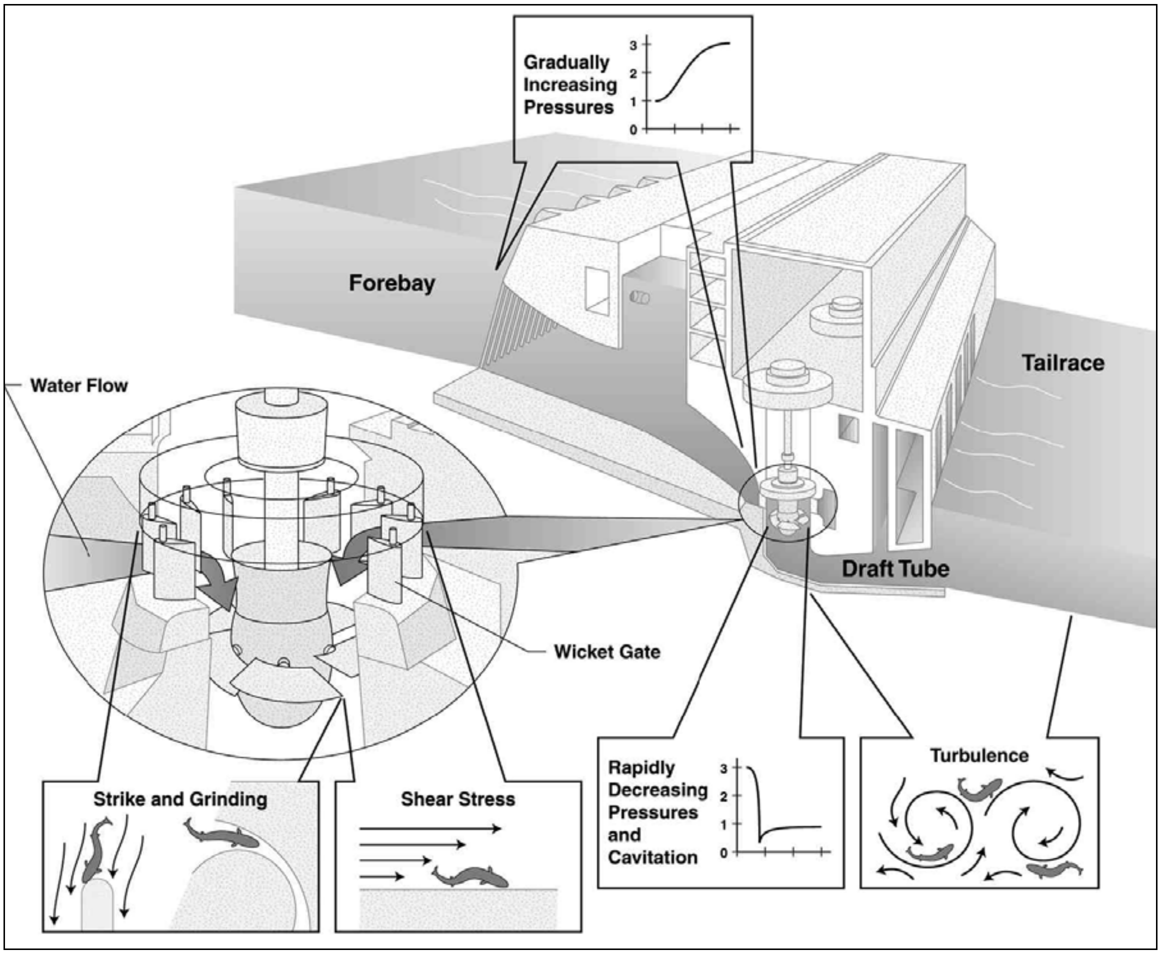


Figure 34: Turbine passage typical locations where fish injuries occur (Cada 2001)

Studies of juvenile salmon have shown that fish reluctantly, after delays in the forebay, enter the turbines intakes. Even then, these fish seek refuge in the gatewells, slots used for inserting solid barriers which keep water from entering the turbines during maintenance (USDOE 2006). Fish that do pass through turbines can become injured or die by a number of mechanisms (Figure 34) including rapid and large pressure changes, shear stresses, cavitation, turbulence, collision with turbine parts, and squeezing through narrow openings between moving and fixed parts (Cada 2001).

The survival of fish during turbine passage is influenced by the size and type of turbine, speed of revolution, and mode of operation, as well as the characteristics of the fish, such as species, size, life-stage, and condition (CEC 2005).

Two types of turbines are generally used at large dams, Francis and Kaplan (Figure 35). The mortality rate for juvenile salmonids passing through Francis and Kaplan turbines varies greatly, from under 5% to over 90% in Francis turbines, and from under 5% to approximately 20% in Kaplan turbines (FAO 2001). Almost all the mainstem Columbia and Snake River dams have Kaplan turbines, which collectively have an average survival (including both direct and indirect effects) of about 88% (Cada 2001). Studies show that a correlation exists between peripheral turbine blade velocity and fish mortality for the Francis design but not the Kaplan design (EPRI 1987). Fish size also affects mortality rate, as larger fish have a greater chance of colliding with turbine parts (OTA 1995).

However, greater hydraulic head does not appear to cause a greater mortality rate in either type of turbine. This conclusion is based on studies of Francis turbines ranging from 40 feet to 410 feet of head and Kaplan turbines ranging from 20 feet to 110 feet of head (Eicher Associates Inc. 1987).

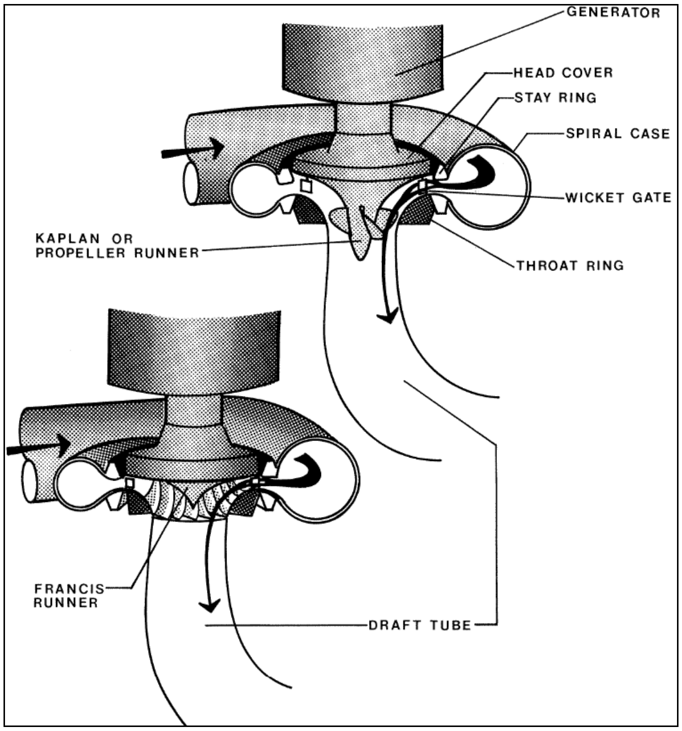


Figure 35: Typical Kaplan and Francis Turbines (Eicher Associates, Inc. 1987)

Francis turbines are commonly used for high head applications and thus are generally used at California large dams. For example, the Shasta and Keswick (Sacramento River), Folsom (American River), Narrows 2 (Englebright Dam on the Yuba River), and New Melones (Stanislaus River) powerplants all have Francis turbines (USBR 2011). In addition, the Hyatt Powerplant at Oroville Dam on the Feather River has 3 Francis generating units and 3 Francis pumping/generating units.

Work has been ongoing to improve fish passage through turbines. The U. S. Army Corps of Engineers has a Turbine Survival Program aimed at investigating and improving juvenile fish passage through turbines. Phase 1 of their study (2004) had the following objectives:

- Evaluate and recommend operational criteria to improve the survival of fish passing through the Kaplan turbine units.
- Identify the biological design criteria for the design of modifications to the existing turbines.
- Investigate modifications to the existing designs that have the potential to increase survival of fish passing through the Kaplan turbine units.
- Recommend a course of action for turbine rehabilitation or replacement that incorporates improvements for fish passage survival.

Spillways

A spillway is one channel or a series of channels along the top of the dam that allow water to pass over the dam (Figure 36). Water is passed through the spillway to release excess flows and to assist in juvenile fish migration. Spillway use by hydroelectric projects along the Columbia River and lower Snake River is fairly common, due to the lack of water storage availability in their reservoirs. At these projects, typically any flow in the river above their designed hydraulic capacity (flow through the turbines) is spilled. In larger water storage and flood control projects in California and the Pacific Northwest, spillways are rarely used, generally only to release water when the reservoir is full.

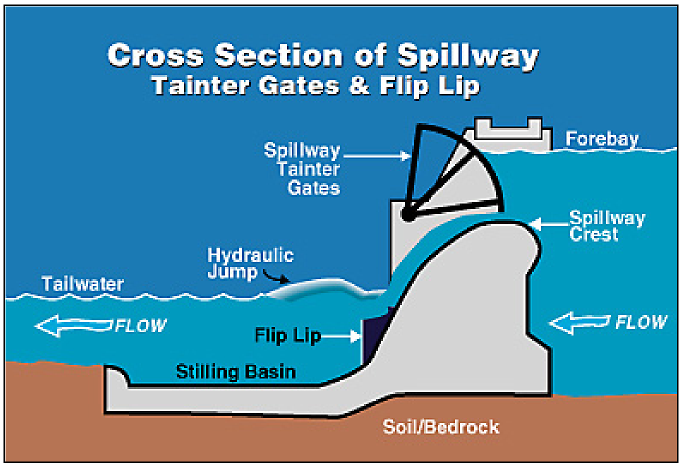


Figure 36: Spillway cross-section (USACE)

Spillway passage is the simplest way to keep fish away from turbines and move them past a hydropower dam (OTA 1995). It can also be cost effective when the juvenile migration period is short, when migration happens during higher flows events, or where spillway releases are needed for other reasons (OTA 1995). However, in the Colombia River system, spill during the low-flow periods of July and August (for late-migrating fall-run Chinook salmon) is economically expensive. It was estimated that ending spill in August during a normal flow year would generate about $38 million dollars in additional revenue for the federal power system (USDOE 2006). That being said, spillway passage is thought to be an effective means for passing juvenile salmonids around turbines at hydroelectric projects in the Pacific Northwest (EPRI 1998). For the lower Snake River Dams, about 98 percent of fish passing through the spillway survive past each dam (USACE 2002).

However, there are risks associated with using spillways for fish passage. These include gas supersaturation, direct injury or mortality, and indirect mortality. Spilling water entrains air as it plunges into the tailwater of the dam, causing higher levels of gas supersaturation, which at high levels can be harmful to juvenile fish, as well as adult migrants and other aquatic species. Flow deflectors (flip lips) help fish passage by producing a more horizontal spill pattern and limiting the depth of the plunge into the tailwater of the dam. The deflectors are in place at seven of the eight USACE dams on the Columbia and Snake rivers (USACE 2011a).

Direct injury or mortality at spillways can have several causes including shear effects, abrasion against the spillway, turbulence in the basin at the base of the dam, sudden velocity and pressure changes as fish enter the stilling basin, and impacts against energy dissipators (FAO 2002).

Indirect mortality can occur at the base of the dam, where turbulence causes disorientation and increased susceptibility to predation (USACE 2002).

In addition to these risks, at the USACE lower Columbia and Snake River dams, juvenile fish must dive 50 or 60 feet to find the spillway passage route (USACE 2004). Two technologies that address the problem are the Removable Spillway Weir and the Temporary Spillway Weir.

Removable Spillway Weirs

A removable spillway weir (RSW) is a steel structure that is installed upstream of the existing spillbay (USACE 2002). It has been used on the Columbia and lower Snake Rivers to pass juvenile salmonids over a raised spillway crest (Figures 37 and 38), similar to a waterslide. Since most Columbia River juvenile salmonids tend to stay in the upper 10 to 20 feet of the water column, the RSW reduces migration delays and provides a less stressful dam passage route by allowing them to pass the dam near the water surface at lower water velocities and pressures (USACE 2004).

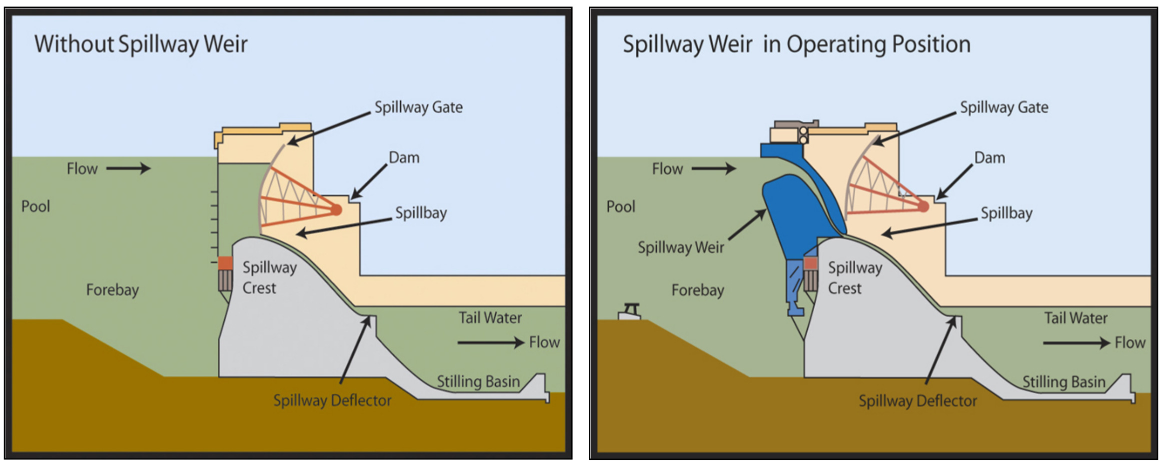


Figure 37: Dam with and without a Removable Spillway Weir (USACE 2011)

Figure 38: RSW in operating and non-operating positions (USACE 2011)

The first installation of the RSW by the Corps of Engineers was at Lower Granite Dam on the lower Snake River in 2001. Subsequently, RSWs were installed at Ice Harbor Dam in 2005 and at Lower

Monumental Dam in 2008. Studies at Lower Granite and Ice Harbor Dams concluded that the fish passage survival over the RSWs was an average of 98 percent. As its name suggests, he RSW is designed to be removable, and can be lowered to the bottom of the dam forebay. Removing the RSW allows the permanent spillway to return to its original flow capacity during major flood events (USACE 2009).

The advantages of the removable spillway weirs are (USACE 2009):

- Less stressful passage conditions and higher survival
- Greater fish passage efficiency (more fish per unit of flow)
- Delay reduction
- Reduced flow which lowers gas supersaturation and increases power generation
- Removal capability for increasing flow during flood events

Temporary Spillway Weirs

A temporary spillway weir (TSW) is smaller than a RSW, but provides a similar benefit by raising the spillway crest and creating a surface fish passage route (Figure 39). It has a low relative cost, is easier to install than the RSW, and allows more flexibility in biological testing. In contrast to the RSW, the TSW cannot be lowered into the forebay during high flows, but it can be removed by lifting it using an existing gantry crane (USACE 2009).

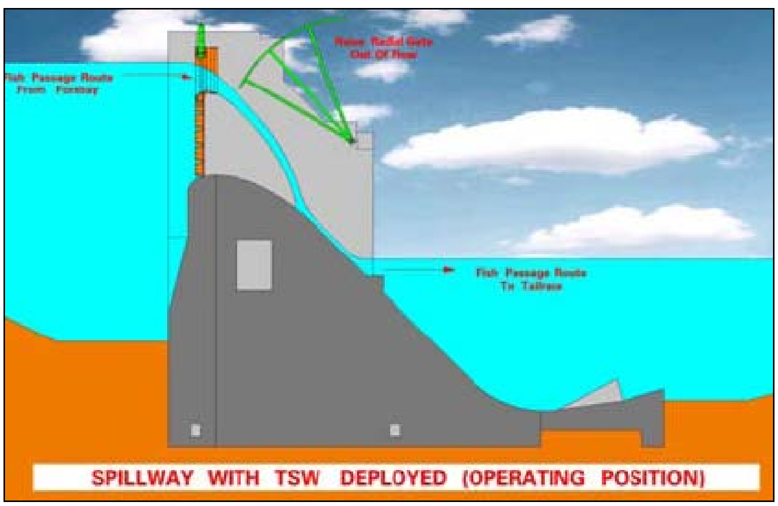


Figure 39: Dam spillway with TSW installed (USACE)

Two TSWs were installed in 2007 at McNary Dam on the Columbia River, and another was installed in 2009 at Little Goose Dam on the lower Snake River. Two styles of TSWs are being investigated. The first has a slide section that comes in direct contact with the spillway, and the other has a crest structure only. Testing of both styles in March 2007 resulted in a 98 percent survival rate (USACE 2009).

Bypass Systems

Bypass systems allow juvenile migrants to pass a dam without going through a turbine or over a spillway. These systems can generally be placed into one of two categories: bypass flumes/pipes to the river downstream of the dam or collection and transport to the river downstream. The method of guidance into the bypass facility (discussed later in the document) can be the same for both categories. Bypass systems have been installed at most of the Columbia River and lower Snake River Dams, as well as some of the large flood control, water storage dams in the Pacific Northwest.

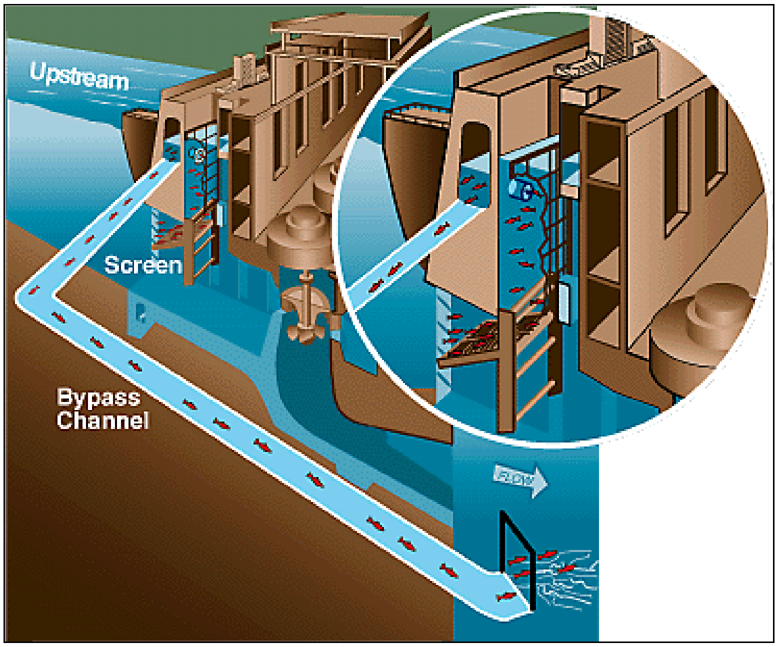


Figure 40: Columbia River juvenile fish bypass system (USACE)

Some of the juvenile fish bypass systems at the lower Columbia and Snake River dams guide fish away from turbine intakes by means of submerged screens (see Gate Well Screen section). This system screens fish up into a gate well where they pass through orifices into channels that run the length of the dam (Figure 40). The channels route fish into a transport holding area or to the river below the dam.

Bypass to Downstream of Dam

Many of the Columbia and lower Snake River dams have bypass systems which pass fish to the river below the dam.

At Rocky Reach Dam on the Columbia River, a permanent surface bypass collection system was completed in 2003. It uses 29 pumps to create a strong flow to attract juvenile fish into the collector. The fish are screened into a bypass pipe which dumps the fish into the river about 2,000 feet downstream of the dam (Chelan County PUD). Use of this bypass reduces the need to use the spillways for fish passage, so that water can be used for generating electricity (USDOE 2006).

At Bonneville Dam on the lower Columbia River, a “Corner Collector” was constructed in 2004 to provide surface passage of downstream migrants. This project consisted of modifying an existing ice and trash chute for safer fish passage. The collector is located at the corner where the Second Powerhouse meets the adjoining abutment. In addition to the chute modifications, a 2,800 foot long transport channel and 500 foot long outfall channel were constructed (USACE 2004). Testing in 2004 and 2005 indicated a survival rate of almost 100 percent for spring- and fall-run Chinook, and steelhead (PNNL 2010).

In addition to the Columbia and lower Snake River dams, large dams built for flood control and water storage also use bypasses which lead directly to the river downstream. At Tacoma Power's Cowlitz River Project in Washington, Mayfield Dam (250 feet tall) has a downstream migrant fish bypass facility which was constructed in the early 1960s. It consists of two vertical louver intake structures, a bypass channel to a fish sorting area, and a bypass pipe and chute to the river downstream (NMFS 2004).

Collection and Transport

Juvenile downstream passage by transport encompasses both trap and truck operations and barging. This method of passing fish around hydropower facilities is used for numerous reasons (OTA 1995, USACE 2008):

- To mitigate the loss of fish in long reservoirs behind dams
- To avoid the impacts of nitrogen supersaturation that may be associated with spilling water
- To avoid the impacts of contaminated water
- To help avoid turbine entrainment, predation, delay, and other issues associated with passing fish downstream of dams

Barges and trucks are used to move juvenile salmonids downstream in the Columbia River Basin to decrease the time it takes for outmigrants to move through the system. Barges are used when the numbers of juvenile salmonids are the highest and trucks are used during the early and late period of the runs when there are fewer fish to move (USACE 2008). Three dams on the lower Snake River (Lower Granite, Little Goose, and Lower Monumental), as well as McNary Dam on the lower Columbia River have fish collection and transport facilities (USACE 2011b). After being trucked or barged downstream, the fish are released below the lowest dam, thereby avoiding turbine entrainment and exposure to predators at intervening dams and reservoirs.

Survival can be high, as the rate for juvenile fish transported from the lower Snake River Dams to the release point below Bonneville Dam is 98 to 99 percent (USACE 2002). However, depending on flow rates, points of collection, holding time, and points of release, juveniles may experience delay in their migration. Delay can have a negative effect on their physiological development (such as smolting) critical to their survival. Exposure to diseases, stress, and disorientation may also occur. In addition, there is evidence that transportation from rearing to release sites does affect salmon's homing ability. The amount of the effect is dependent on the life stage of the salmon, the transportation method, and the distance between rearing and release sites. Results of studies have shown that juvenile salmonids trucked long distances tend to return to their release site instead of their rearing site (OTA 1995).

Large flood control, water storage projects in the Pacific Northwest also use collection and transport to move juvenile salmonids downstream. At Cowlitz Falls Dam, the uppermost dam on the Cowlitz River, outmigrating juvenile fish (spring-run Chinook salmon, coho salmon, and steelhead) are collected and trucked past Mossyrock and Mayfield Dams to the Cowlitz Salmon Hatchery for release (NMFS 2004). Similarly, on the Deschutes River, juveniles are collected at Portland General Electric's newly completed tower fish facility in Lake Billy Chinook and trucked downstream past three dams

(PGE 2011b). Another example is the Baker River Project. Juveniles are collected at Puget Sound Energy's floating surface collector at Upper Baker Dam and trucked past Lower Baker Dam to the river downstream (PSE 2010). The Case Studies section in this document has more detail on these projects.

Downstream Screening and Guidance Technologies

For downstream passage of juvenile salmonids, screening and guidance technologies consist of physical barriers, structural guidance devices, and behavioral barriers. At dams, these technologies can guide fish away from turbines intakes, water diversions, and spillways (or in some cases to spillways), and into a bypass or collection facility. Physical barriers are the most commonly used technology for protection of juvenile migrants, and include many kinds of screens that exclude fish and protect them from entrainment. They provide a positive barrier, not allowing any fish to pass. Based on experience and evaluations of their performance, they are usually recommended in the Pacific Northwest and California (OTA 1995). Barrier nets are also included in this category, because even though they may allow fish to pass under or around the net, the actual net is a physical barrier. Structural guidance devices, such as angled bar racks or louvers are used to guide fish by eliciting a response to specific hydraulic conditions. Since these devices have arrays of vertical slats or bars with spacing larger than the width of the target fish, they do not create a 100% effective barrier. They use the turbulence created by water moving along the slats to keep fish from moving between the slats (CEC 2005). Finally, the use of behavioral barriers, such as lights or sound continues to be explored. These devices have not been proven to perform successfully under a wide range of conditions. Therefore, resource agencies consider them to be much less reliable than properly designed and maintained physical barriers (OTA 1995).

The United States Bureau of Reclamation's Fish Protection at Water Diversions document has information on screening and guidance technologies, with some detailed case studies. It can be found at http://www.usbr.gov/pmts/hydraulics_lab/pubs/manuals/fishprotection/index.html.

Physical Barriers

Physical barrier screens installed and evaluated in the last 20 years at facilities in the Pacific Northwest and California show a nearly 100% guidance efficiency (CEC 2005). Design criteria vary between agencies, but generally address approach and sweeping velocities, size of screen openings, and types of materials. Designs must be customized to an individual site and the target fish species (OTA 1995). Screens can be flat or curved, vertical or inclined, stationary or moving, and can be made of many different materials, such as perforated steel plate, metal bars, wedgewire, or plastic mesh, based on the application and type of screen. Screens are designed to eliminate entrainment and impingement of fish.

The primary design consideration is that the water must have low approach velocities perpendicular to the screen and a higher, steady sweeping velocity parallel to the screen. The swimming ability of the target species will determine the acceptable approach velocity. Consistent approach velocities at every point on the screen are desirable, because localized high velocity areas increase the potential for fish injury and debris accumulation (CEC 2005). The positioning of the fish screen is critical, as it must be in an appropriate relationship to the water being diverted and bypassed to create the appropriate hydraulic conditions (OTA 1995). Some physical barrier screens, such as the Eicher Screen and Modular Inclined Screen, have approach velocities that do not meet regulatory criteria, but do have very high sweeping velocities to get fish past the screen before they are impinged.

In California, the National Marine Fisheries Service provides criteria for the screening of anadromous salmonids, and the California Department of Fish and Game recommends screening criteria for all diversions. These criteria identify acceptable approach and sweeping velocities, screen material and mesh size, and maintenance requirements (CEC 2005).

Debris is commonly one of the biggest problems at fish screens and associated bypass facilities. Debris loads can disrupt flow through a screen, creating high velocity areas, or can cause injury to fish as they move along a screen. In addition, for screen facilities with fish bypasses, a partially blocked bypass entrance can reduce fish passage efficiency and cause injury or mortality. A screen cleaning system will help alleviate screen debris loading. Automatic, mechanical cleaning systems are preferable over manual ones and are generally more reliable (albeit more expensive), provided they are working properly. Regular inspections, to ensure proper operation of the facility, are important to increase effectiveness (OTA 1995).

The sections below have descriptions of some specific designs of a variety of physical barrier screens.

Gate Well Screens

Gate well screens, or turbine intake screens, are used at large hydropower facilities on the Columbia and Snake River system (EPRI 1986, 1994a, 1999; Bell 1991 in CEC 2005). The screen is placed in the turbine intake and blocks only the upper portion of the intake. Therefore, their best use is at sites with large intakes where fish are concentrated in the upper portion of the intake (CEC 2005).

At some sites, gate well screens intercept over 75% of smolts entrained by the intake.
At sites where fish are not concentrated near the surface, efficiencies can be less than 30% (INCA Engineers 1999 in CEC 2005). Screened fish are bypassed or collected and transported around the dam. There are no gate well screen installations in California (CEC 2005).

Drum Screens

The rotary drum screen is frequently used in the Pacific Northwest (WDFW 2000a). It is a screen-covered, rotating cylinder placed in a diversion channel with the cylinder axis oriented horizontally. A facility can consist of one or a series of drum screens placed end-to-end across the flow section, usually with a fish bypass at the downstream end of the screen(s) (Figure 41). Seals are placed between the screen and bottom and end surfaces. Each drum screen rotates slowly about its axis and must be kept at 65% to 85% submergence for effective performance. The advantage of the screen is that as it rotates, it continuously removes debris by carrying it over the screen and passively cleaning it off the screen as it submerges on the downstream side. Screen rotation can be achieved by a motor or paddlewheel (WDFW 2000a).

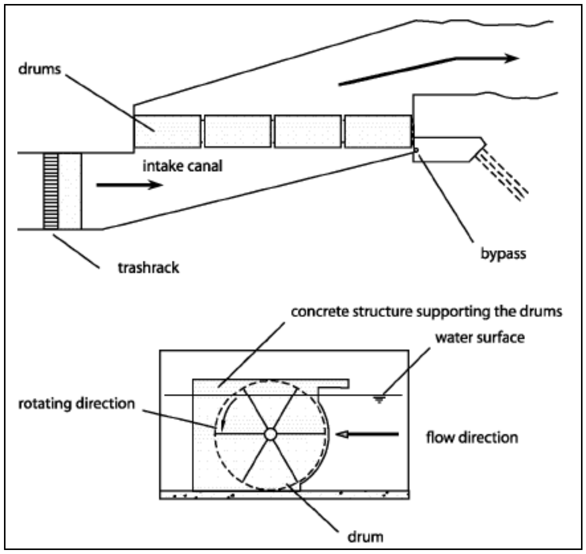


Figure 41: Rotary Drum Screens (EPRI 1994)

Rotary drum screens can be used for a range of diversion types and have been used for diversions as low as a few cfs up to more than 3,000 cfs. They are generally used for gravity diversion canals but can also be used at pumping plants. The screen is very effective in protecting juvenile fish, as studies have found a survival rate of greater than 98% (WDFW 2000a).

The main disadvantage of the drum screen is, because of its movement, leakage or failure of the side and bottom seals can result in fish entrainment or impingement. Therefore, the seals must be frequently monitored and require greater maintenance in comparison to other types of screens. Another disadvantage of the drum screen is the narrow range of water levels within which it can operate. For example, to maintain appropriate submergence for a 10-foot-diameter screen, the forebay water surface can vary by no more than 2 feet (WDFW 2000a).

An example of a rotary drum screen facility is the Roza Diversion Dam on the Yakima River in Washington State (Figure 42).

Figure 42: Roza Diversion Dam Drum Screens, Yakima River, WA (USBR)

Fixed Flat-Plate Screens

Fixed flat-plate screens consist of a series of screen panels placed vertically, inclined, horizontal, or sloping.

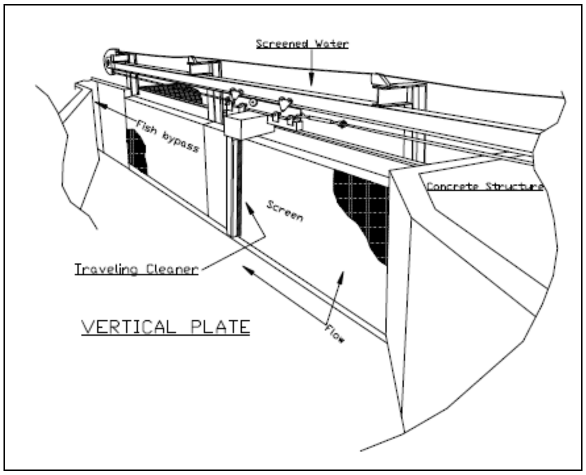


Figure 43: Vertical Flat-Plate Screen (WDFW 2009)

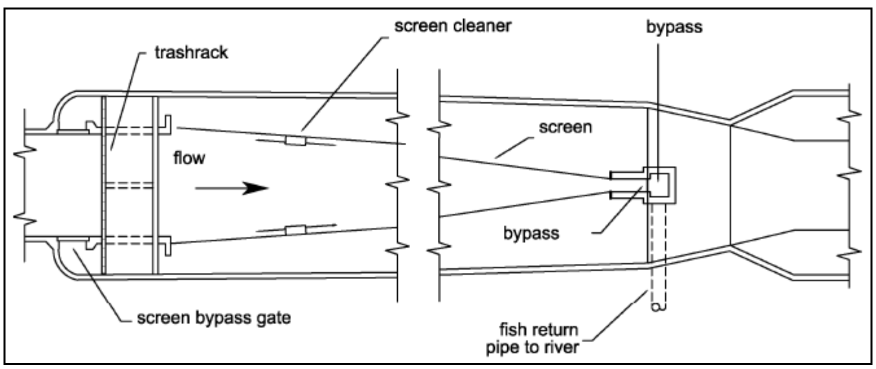


Figure 44: Fixed Flat-Plate screen in "V" configuration (EPRI 1994)

Vertical and Inclined Fixed Flat-plate Screens

The vertical and side-tilted inclined screens can compose a single face or converging faces forming a “V” (Figures 43 and 44). The main benefit of these types of screen are that they have a continuous smooth face which minimizes obstacles to fish passage and simplifies cleaning (CEC 2005). The screens are set at a slight angle to converge at the bypass at the downstream end of the channel to keep sweeping velocities relatively uniform along the screen face as water is diverted through the screen.

Advantages of the fixed flat-plate screen are that they are easy to seal and, because there are no moving parts, are mechanically simple. However, debris removal is an important design consideration for these screens and generally a mechanical cleaning system is required for debris removal. Typically used cleaning systems include traveling brush type cleaners and water backwash systems. Cleaning system operation can be triggered by either a timer or by a unit that detects head loss across the screen, or by a combination of both (WDFW 2000a).

Examples of fixed flat-plate screens at smaller facilities in California are the vertical flat-plate “V” screen at the Anderson Cottonwood Irrigation District diversion on the Sacramento River near Redding (Figure 45) and the inclined flat-plate screen at the Rancho Esquon diversion on Butte Creek near Chico (Figure 46). Examples of uses at larger hydropower facilities are the "V" screen intakes for the Pelton Round Butte Hydroelectric Project's juvenile collection facility atop the $108 million dollar Selective Water Withdrawal Tower in Lake Billy Chinook and the Baker River Hydroelectric Project's floating surface collector in Upper Baker Lake (please see the case studies for these projects). At hydropower facilities in California, these types of screens are used at the Beaver Creek Diversion, part of the North Fork Stanislaus River Hydroelectric Development Project, and the Kilarc-Cow Creek Project on South Cow Creek (CEC 2005).

Figure 45: ACID Diversion Vertical Flat-plate Fish Screen in "V" Formation, Sacramento River, CA (CA Dept. of Water Resources)

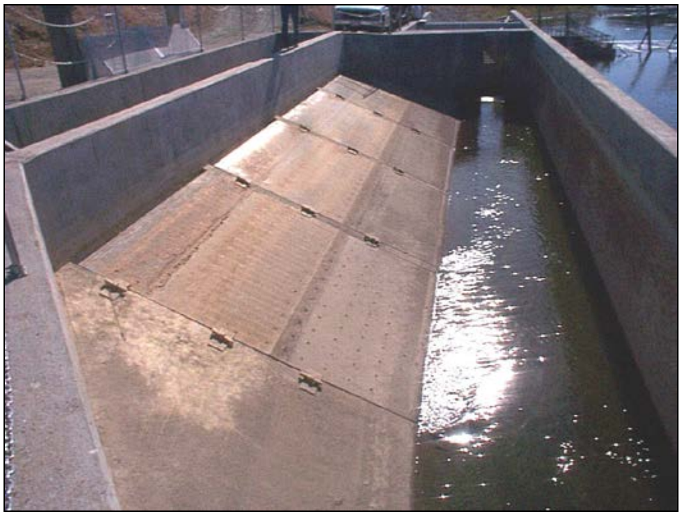


Figure 46: Rancho Esquon Inclined Flat-plate Fish Screen, Butte Creek, CA – Shown at a low forebay elevation (CA Dept. of Water Resources)

Horizontal and Sloping Fixed Flat-plate Screens

Other possible configurations of fixed flat-plate screens include placing them in horizontal or sloping positions. The main advantage of these types of screens is that there are no moving parts. Disadvantages include the potential for inadequate debris removal and shallow or no depth on the downstream end of the screen potentially causing fish injury (WDFW 2000a).

Horizontal Flat-plate Screens

The horizontal flat-plate screen concept uses a screen placed near the bottom of a natural channel. The horizontal screen is usually applied in small rivers and can be used in conjunction with either a gravity or pumped diversion. The horizontal flat-plate screen is relatively inexpensive, has no moving parts, and allows placement with significant active surface area in a shallow stream. Therefore, the concept is more applicable at shallow sites than vertical flat plate screens or fixed cylindrical screens (USBR 2006).

Components of a typical horizontal flat-plate screen include the screen**,** an adjustable side weir that controls the diversion and ensures that the chamber below the screen will not be dewatered if a complete debris blockage occurs, and a sediment trap, located upstream from the screen, that prevents bedload movement across the screen. The design generally does not require baffling to generate uniform screen approach velocities (USBR 2006).

Disadvantages of horizontal flat plate screens include unproven debris and sediment handling, varying flow rates due to water surface elevation fluctuations and screen fouling, and high exposure of bottom-oriented fish to the screen surface (USBR 2006).

Downward Sloping Fixed Flat-plate Screens

The downward sloping screens have only a portion of the total flow traveling across the screen passing through it (Figure 47). The flow that passes through the screen falls into a channel situated below the screen. Fish pass over the screen with the remaining flow. These screens function effectively, in terms of fish passage, only if a sufficient flow depth exists at the downstream end of the screen. A minimum

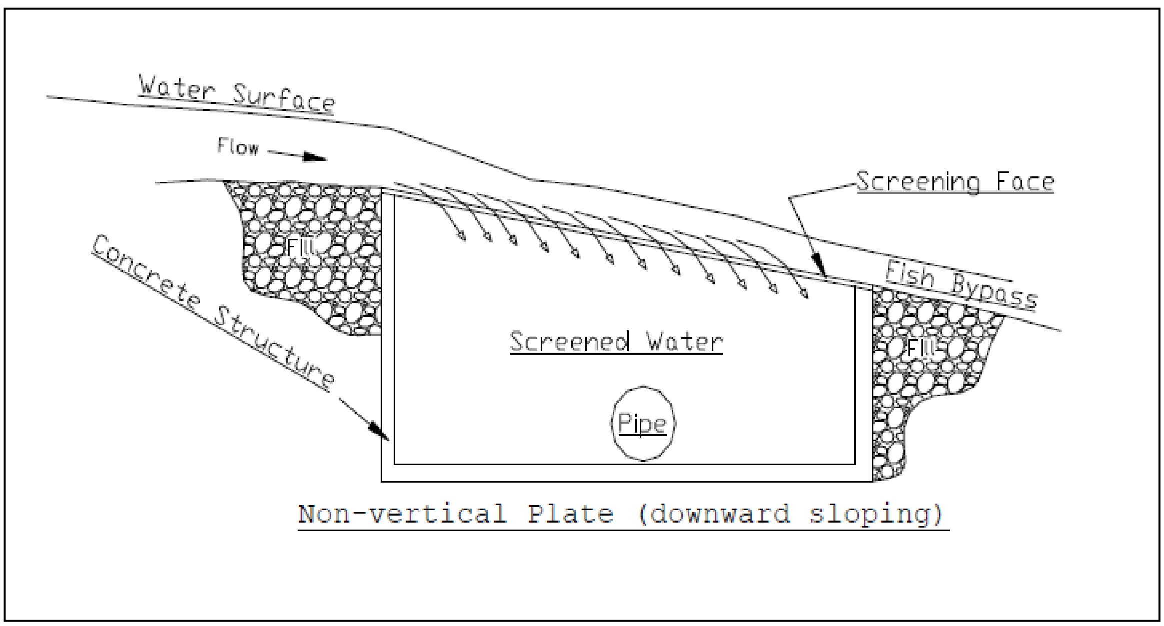


Figure 47: Downward sloping fixed flat-plate screen (WDFW 2009)

depth of water should be based on expectations of size and type of potential debris, and size of fish passing. The screens must be carefully operated to ensure proper depth conditions (WDFW 2000a).

Downward sloping screens are generally used for gravity diversions. Flow distribution through the screen is usually not uniform since water depth over the upstream end of the screen is greater than over the downstream end. Baffling systems have been used behind the screen to uniformly distribute approach velocities, but these have not been proven, reliable and easily operable (WDFW 2000a).

Coanda Screens

A version of the downward sloping screen that does not have a flat-plate is the Coanda screen (Figures 48 and 49). Typically, the Coanda screen has a concave face, consisting of wedge-wire, and its contoured shape is designed to mimic the nappe of water as if it were free spilling. Because the flow follows the contour, the distribution of flow through the screen is more uniform (WDFW 2000a).

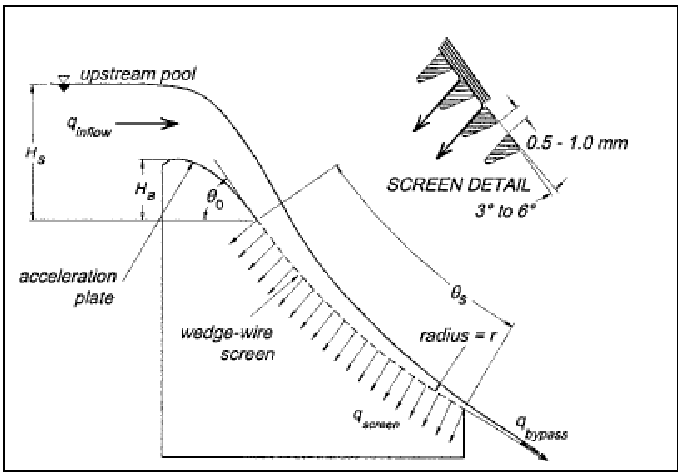


Figure 48: Coanda Fish Screen (Wahl 2003)

Figure 49: Montgomery Creek Coanda Fish Screen (Wahl 2003)

Coanda screens are generally installed on downstream faces of overflow weirs. Water passes over the crest of the weir and a solid acceleration plate, and then flows across and through the screen. Flow that passes through the screen is collected in a channel below the screen and the remaining water, containing debris and fish, passes over the downstream end of the screen. Water velocities across the screen are relatively high, typically ranging from 6 to12 fps, and are a function of the height from the upstream pool to the top of the screen. Sufficient depths must be maintained over the downstream portion of the screen to prevent fish contact with the screen (USBR 2006).

Compared to traditional fish screens, impingement of fish against the Coanda screen is not a significant concern, since the high sweeping velocity carries fish quickly off the screen. However, additional biological testing is needed to demonstrate fish survival and evaluate other side effects, such as descaling injuries, disorientation, and delayed passage. Some advantages of the Coanda screen are that it is relatively compact, has no moving parts, improves water quality at sites with low dissolved oxygen levels, is essentially self-cleaning, and is easily manually cleaned if debris does accumulate. Disadvantages include the requirement of several feet of head drop and a substantial amount of bypass flow, that the concept may be considered developmental by fisheries resource agencies (since the possibility of fish injury and mortality has not been fully evaluated and documented), and that applications are likely limited to relatively small diversions (USBR 2006).

Examples of Coanda screens in California are the Panther Ranch Hydroelectric Project in Shasta County, Bear Creek Hydroelectric Project in Shasta County, Montgomery Creek Project in Shasta County, and Bluford Creek Hydroelectric Project in Trinity County. Because of limited biological evaluations of the Coanda screen, it is not yet considered acceptable for anadromous fish screening in California (CEC 2005).

Upward Sloping Fixed Flat-plate Screens

The profile of upward sloping screens rises in the direction of the water flow (Figure 50). Because the screen is backwatered from below, water does not drop through the screen, but flows through the screen.

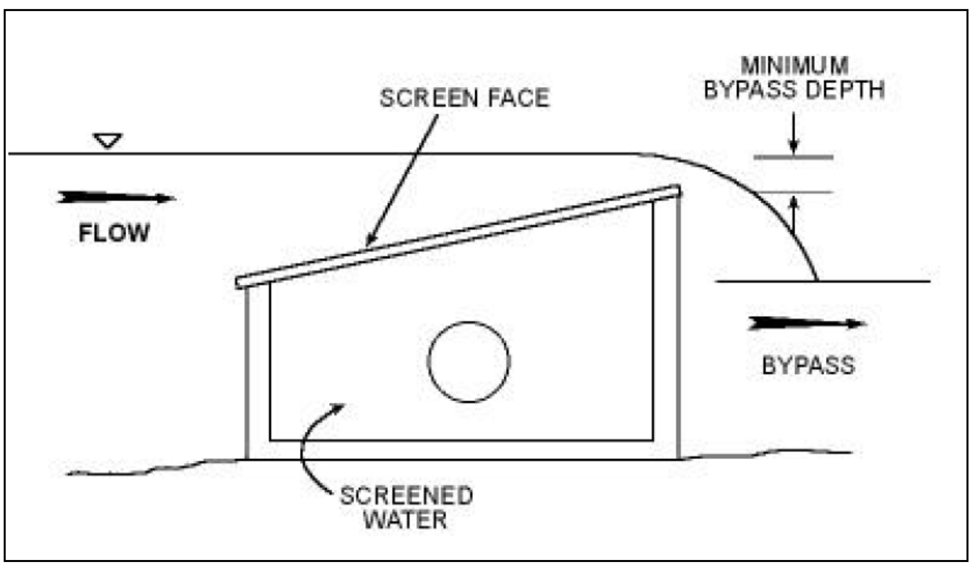


Figure 50: Upward sloping fixed flat-plate screen (WDFW 2000a)

A small amount of water flows over the downstream end of the screen creating the fish and debris bypass (WDFW 2000a).

This type of fish screen is generally used for gravity water diversions, but can also be used with a pump providing flow through the screen. The main advantage of this type of screen is that there is a fairly uniform flow distribution through the screen. Except for automatic cleaning devices, the design is relatively simple (WDFW 2000a).

A primary disadvantage of the screen is that debris is not automatically swept off the screen, and must be cleaned off the screen. There is a serious risk of structural failure if the cleaning mechanism fails. Another disadvantage is that fish may reject the screen and the bypass. The rejection is possibly due to the low depth at the upstream end of the screen, and therefore a depth of at least one foot is needed there to get fish into the bypass system. A third disadvantage is that there is little if any flexibility in upstream water surface elevation. If the upstream water level drops too low, the minimum bypass depth criteria will not be satisfied and if the water level rises too much, excess water is put into the bypass system. (WDFW 2000a).

An example of an upward sloping fixed flat-plate screen is the Pelton Skimmer, located in Lake Simtustus on the Deschutes River . The Pelton Skimmer is used for fish passage only and not for the diversion of water, as all flow through the screen is returned to the reservoir (Ratliff et al 2009).

Non-Fixed Flat-Plate Screens

Non-fixed flat-plate screens include the Eicher Screen and the Modular Inclined Screen. These flat-plate screens are upward sloping screens installed in a closed conduit, are axle mounted so that they can be rotated for cleaning, and are considered to be high velocity screens. No high velocity screens are installed in California (CEC 2005).

Eicher Screens

The Eicher screen was developed in the late 1970s to provide a better means of bypassing fish around a turbine (Figure 51). The elliptical screen is designed to fit inside a penstock at a relatively shallow angle and functions in velocities up to 8 fps. The Eicher screen’s ability to handle high velocities distinguishes it from conventional fish screens, which generally operate at channel velocities of about 1-2 fps. Other advantages are low installation, operation, and maintenance costs, and the ability to handle changes in the forebay elevations (OTA 1995).

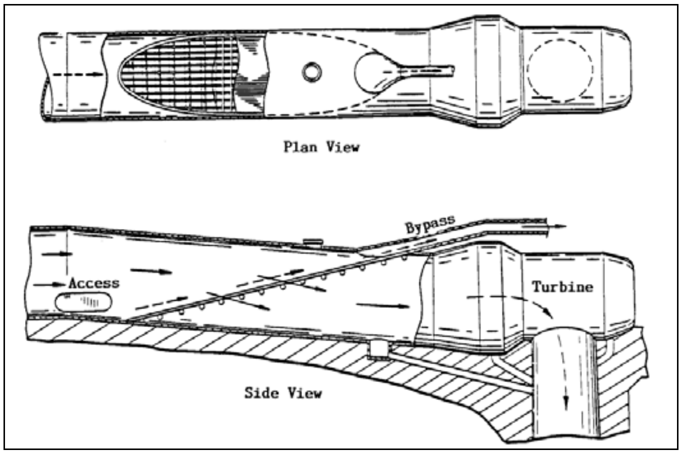


Figure 51: Eicher Fish Screen (EPRI 1987)

Pivoting the screen panel generates a backwash flow which cleans the screens. Backwashing may be part of a routine cleaning operation or may be initiated by a pressure drop across the screen. The backwashing does not interrupt power generation (CEC 2005).

The Eicher screen has approach velocities that violate most state and federal screening criteria. However, research and evaluation of the screen has led to approval from agency personnel who were not convinced of their applicability earlier (OTA 1995). Another disadvantage of the screen is that it bypasses fish only during power operations and does not support fish passage when reservoirs are filling and power operations are not occurring (CEC 2005).

The Eicher screen has a significant history of field application. It has been used at Portland General Electric's T.W. Sullivan Plant since 1980, and at British Columbia Hydro's Puntledge Plant in British Columbia since 1993. In addition, a prototype has been studied for multiple years at the Elwha Hydroelectric Plant in Washington State (USBR 2006).

Modular Inclined Screens

The Modular Inclined Screen is a high velocity fish screen concept similar to the Eicher screen, but designed for a conduit of rectangular cross section. The screen consists of a rectangular flat-plate screen (made of wedge-wire) which rises up from the bottom of the conduit at a slight angle, typically 10 to 20 degrees. The Modular Inclined Screen is axle-mounted like the Eicher screen, so it is cleaned by pivoting the screen and allowing the flow to backwash it. Scale-model tests carried out to study the hydraulic characteristics of the screen and fish behavior in the vicinity of the screen have provided promising results, with a survival rate of over 99% at high approach velocities (EPRI 1994).

Traveling Screens

Traveling screens are mechanical screens installed either vertically (Figure 52) or on an incline. The screen operates with the screen rotating (traveling), either intermittently or continuously, to keep the screen clean. The screen material moves up on the upstream face and down on the downstream face (USBR 2006). Similar to drum screens, the mesh of vertical traveling screen removes debris collected on the screen face, depositing it on the downstream side (WDFW 2000a).

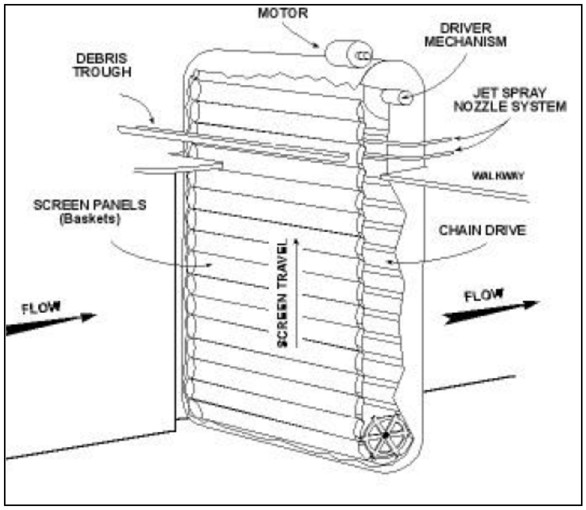


Figure 52: Vertical Traveling Screen (WDFW 2000)

The screen drive motor is positioned above the water surface, but many parts are submerged at the bottom of the screen. Sediment around this lower area may increase maintenance requirements (USBR 2006).

The traveling screen can also be installed completely underwater in the intakes to hydropower plants. These submersible traveling screens are expensive and can have mechanical failures, but at some locations have been considered by the USACE to be the best available technology for screening downstream migrating fish in the Columbia River system (Ruggles 1991 in OTA 1995). On the Columbia River, submersible traveling screens operate continuously during the four- to nine-month salmonid downstream migration period. They are capable of screening large flows, but do not screen the entire flow in the intake (Pearce 1993 and Ruggles 1991 in OTA 1995). These screens work best at facilities where the fish are mainly in the upper portion of the water column (EPRI 1986 in OTA 1995). At intakes that are deep (i.e., greater than 90 feet) and have high flows, fish can move away from the screens. The potential for impingement on the screens is greater due to high through-screen velocities (Pearce 1993 in OTA 1995).

Advantages of traveling screens are that they have excellent debris handling characteristics, can be installed in deep water, do not require a controlled operating water depth for proper cleaning, have been widely applied for many years, have a good performance record, and are accepted by fisheries resource agencies (USBR 2006).

Disadvantages of traveling screens are that they are not as economically feasible for large diversions, they require regular maintenance, and they can have seal problems due to the mesh panels articulating when they rotate around the idler shaft at the bottom of the screen (USBR 2006, WDFW 2000a).

Barrier Nets

Where conventional screening structures are not financially feasible, barrier nets may provide a cost-effective means of protecting fish from entrainment. Barrier nets of nylon mesh can provide fish protection at many types of water intakes, including hydropower and pumped storage facilities. The nets are generally about a tenth the cost of most alternatives, but they may not be suitable for many sites. Their success in excluding fish depends on local hydraulic conditions, fish size, and the type of material (OTA 1995). Barrier nets exclusion efficiencies generally range from 70% to 100% (EPRI 1986, 1994b, 1999; Guilfoos 1995 in CEC 2005). Barrier nets are most effective in areas with minimal wave action, light debris loads, and low approach velocities. Biofouling can cause performance problems, but manual cleaning and special coatings can help lessen this problem (OTA 1995). Barrier nets should not be used at sites where there is concern for the entrainment of very small fish, where ice and debris are prevalent, or where passage is considered necessary (Smith 1995 in OTA 1995).

That being said, barrier nets are being used in reservoirs to guide fish into conventional fish screening facilities. At Upper Baker Lake on the Baker River in Washington State, a shore-to-shore, surface to lakebed barrier net guides downstream migrants into a floating surface collector. Barrier nets are also being considered for other reservoirs where floating surface collectors will be deployed.

Most barrier net applications are for seasonal use. In California, no hydropower facilities use barrier nets to exclude fish, but if they were considered for use, they would likely need to be installed year-round, which would make maintenance difficult (CEC 2005).

Structural Guidance Devices

Angled bar racks (trash racks) and louvers generally consist of numerous vertical slats placed on a diagonal across a channel and are used to guide juvenile fish toward fish bypasses. The spaces between the slats are larger than the fish of interest, so they are not a physical barrier. Instead, they create turbulent conditions that fish avoid and the fish move along the structure with the sweeping flow into a bypass system (USBR 2006). Angled bar racks have slats directed into the flow, typically 90 degrees to the structure to which they are attached, while louvers have slats at a 90 degree angle to flow (Figure 53). The success of these systems is dependent on how well they perform under changing hydraulic conditions and for the range of fish using the facility (OTA 1995).

Angled Bar Racks

Angled bar racks have been one of the most frequently used fish protection systems for hydropower projects, particularly in the northeastern United States (EPRI 1994 and USDE 1991 in OTA 1995). Most of the angled bar racks facilities have arrays of slats installed at a 45-degree-angle to flow and consist of 1 to 2 inch spaced metal bars (Amaral et al 2008) with a maximum approach velocity of two feet per second (Bates 1992 and EPRI 1994 in OTA 1995).

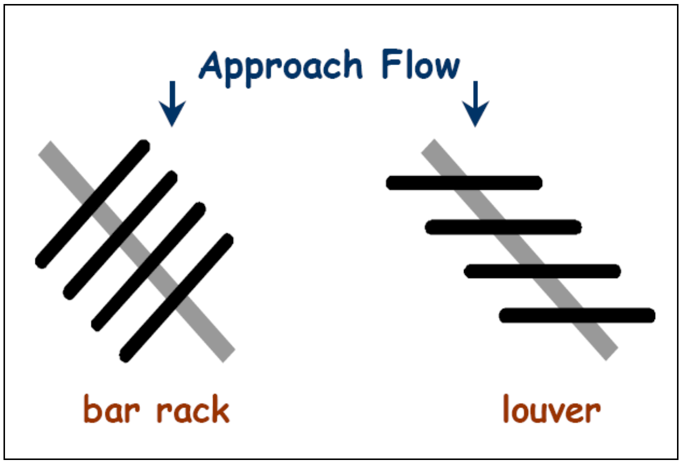


Figure 53: Angled bar racks and louvers (Amaral 2003)

The angled bar rack has more closely spaced bars than conventional trashracks, so it can physically stop large fish from passing through the slats. However, it can divert small downstream migrating fish and the closely spaced slats create the potential for impingement of fish (OTA 1995). Studies of effectiveness have shown mixed results, usually dependent on hydraulics and fish behavior (Amaral et al 2008).

Proper maintenance of angled bar racks is a critical element for operational success. Racks can have mechanical cleaning systems or can be pulled out of the water for manual cleaning (Bates 1992 in OTA 1995).

Louvers

Louver arrays must be set at a certain angle (from 11° to 40°) in relation to flow and the efficiency decreases when the angle increases. The average spacing between slats varies in relation to species and regulatory requirements, with a decrease in spacing from upstream to downstream reducing the velocity required at the bypass (Therrien and Bourgeois 2000).

Exclusion efficiencies for louvers range from greater than 90 percent for juvenile Chinook salmon with fork lengths longer than 45 mm (1.77 inches) to below 30 percent for those with fork lengths shorter than 30 mm (1.18 inches). Numerous studies have been conducted to evaluate louver efficiencies as a function of design parameters, but considerable uncertainty still exists in the development of a specific louver design for a specific fishery (USBR 2006).

Examples of louver installations include the Department of Water Resources Skinner Fish Facility and the USBR's Tracy Fish Facility, both near Tracy, California, and the Mayfield Dam facility on the Cowlitz River in Washington.

Structural guidance devices are an appealing fish exclusion option because they are fairly inexpensive and the spacing between slats is relatively large, allowing for sediment and debris passage. These facilities can also operate at higher velocities than typical fish screens, which allows for a smaller overall structure footprint. They often can be an effective exclusion option for stronger swimming fish and can provide a cheaper option at sites where 100 percent fish exclusion is not required (USBR 2006).

Disadvantages of structural guidance devices are that they are not a physical barrier and therefore do not provide 100 percent exclusion. In addition, mechanical equipment is required for cleaning and debris handling. Depending on debris type and quantity, cleaning and debris handling demands may be substantial. Further, some fibrous aquatic plants and woody plants can intertwine in the bars, which leads to difficult debris removal and cleaning. Finally, even though they have been installed on the West Coast of the United States, structural guidance devices are typically opposed by resource agencies there (USBR 2006).

Behavioral Barriers

In general, physical barrier fish screens are preferred over behavioral barriers by resource agencies. However, physical barrier fish screens can be expensive to construct and maintain. Consequently, the development of alternatives to these technologies, such as behavioral guidance devices, continues to be explored (OTA 1995). Behavioral guidance devices provide various stimuli that are used to guide fish through facilities. At downstream passage facilities some stimuli are natural, such as flow velocity and depth, ambient light, channel shape, and water temperature. Behavioral guidance devices provide other stimuli, such as lights, sound, turbulence, air bubbles, and electrical charge, caused by artificial means (USBR 2006). These devices have not been proven to perform successfully under a wide range of conditions. Thus, resource agencies consider them to be less reliable than physical barriers (OTA 1995).

Lights

Lights can be used either to drive fish away from water diversions and intakes or to attract fish to a desired location. Devices generating wide ranges of intensity, wave band frequency, and duration have been applied. Lights offer a low capital and operation and maintenance cost option for fish guidance. They can be used at sites that are very large, pass large flows that would be difficult or expensive to screen, or that are inaccessible. Lights might also be used at sites where high cost would preclude the installation of a fish screen (USBR 2006).

The primary disadvantage of lights is their inconsistency in excluding or guiding fish. They have been proven effective at some sites which have specific fish species and life stages, but are ineffective at other sites. The performance of lights is strongly influenced by the ambient lighting conditions, which may dominate over artificial lighting. Consequently, when applied at shallower sites, lights are typically effective only at night. Fishery resource agencies typically consider lights to be a developmental and unproven technology (USBR 2006).

Sound

Sound is used to either drive fish away from diversions or intakes, or to guide fish to a desired location. The following devices that generate a wide range of sound magnitude and frequency have been used: mechanical devices, such as the hammer (or fishpulser), fishdrone, and poppers; transducer systems, which use speaker-like equipment to generate frequencies ranging from less than 100 Hz to 190 kHz; and infrasound generators, which use either an oscillating piston or a rotating valve with openings to generate frequencies less than 100 Hz (typically 10 to 60 Hz) (USBR 2006).

As with lights, sound offers a low cost fish control option. They can be used at sites that are very largeor that are inaccessible. Sound can also be used at sites where high cost would preclude the installation of a fish screen. The primary disadvantage of using sound is its inconsistency in generating fish exclusion and guidance. As with lights, sound has been proven effective at some sites with specific fish species and life stages and ineffective at other sites. Fishery resource agencies typically consider lights to be a developmental and unproven technology (USBR 2006).

Air Bubbles

A variety of concepts that establish curtain-like barriers have been developed and applied, including manifolds that release a series of compressed air driven bubble plumes that, in combination, form a bubble curtain (USBR 2006). Air bubble curtains have not been proven to be effective in blocking or guiding fish in a variety of applications, nor is there any data available to indicate potential effectiveness (Taft 1994 in OTA 1995).

Electrical Fields

Electrical fields are used to cause an avoidance response by fish and guide them to a preferred location. However, they have not been proven successful in guiding fish and have had limited success as barriers. Issues such as balancing the power of the electrical field depending on fish size and fish fatigue near the electrical field have not been resolved. Wilkins Slough Pumping Plant (Sacramento River) and USBR personnel worked with various suppliers to test acoustical and electrical fish fields for over 4 years to try to develop a more cost-effective barrier than a physical barrier fish screen. Although there was considerable and valuable data gathered, these types of systems did not prove to be as effective as positive barrier screens and, in most cases, are not accepted as proven fish barriers by fishery resource agencies (USBR 2006).

BGS Behavioral Guidance System

In 2008, a prototype Behavioral Guidance System (BGS) was installed in the forebay of the second powerhouse at Bonneville Dam (Figure 54). The BGS is a 700-foot-long, 10-foot-deep physical barrier, intended to increase the guidance of juvenile salmon to the corner collector fish bypass. The USACE Portland District asked Pacific Northwest National Laboratory (PNNL) to conduct an acoustic telemetry study to evaluate the prototype BGS. The PNNL found the BGS increased passage percentage into the corner collector for yearling Chinook salmon by up to 9%, but no improvements were observed for subyearling Chinook or juvenile steelhead when comparing 2008 study results to passage distributions observed in 2004-2005 radio-telemetry studies. However, it should be noted that in 2004-2005 all turbines were operating, while in 2008 one turbine unit was offline, making it difficult to compare passage percentages (PNNL 2010).

Figure 54: Behavioral Guidance System at Bonneville Dam (Courtesy USACOE)

Dam Removal

As stated in the previous chapter, dams can cause numerous problems to watersheds and affect anadromous fish migrations. Therefore, removing dams can have a positive impact on aquatic ecosystems. From 1999 to 2010, 450 dams were removed in the United States. Recent dams removed in the western United States include Marmot Dam, a 46-foot-high structure removed from the Sandy River in northern Oregon in 2007 (see case study) and Savage Rapids Dam, a 39-foot-high structure removed from the Rogue River in southern Oregon in 2009. In March 2012, the Elwha River (Olympic National Park, Washington) was returned to its original channel after removal of 108-foot-high Elwha dam (Figures 55 and 56). Approximately 9 miles upstream from the former Elwha Dam

Figure 55: Elwha Dam on August 25, 2011 before removal (Courtesy of the National Park Service)

site, 210-foot-high Glines Canyon Dam is currently being removed. On the White Salmon River in

Figure 56: Elwha Dam on April 30, 2012 after removal (Courtesy of the NPS)

southern Washington, 125-foot-high Condit Dam is currently being removed.

Removing a dam can have a short-term negative impact on water quality. If reservoir sediments are not removed or stabilized prior to dam removal, fine-grained material can be re-suspended and cause water quality issues and damage spawning areas downstream. If the sediments contain toxics, the dam removal impacts can be more significant. When a reservoir is drawn down too quickly, supersaturation (water containing more dissolved gases than normal) can occur as the result of high water velocities in a stream, negatively impacting downstream organisms. For example, when the Little Goose Dam on the Snake River in Washington was drawn down in 1992, supersaturation occurred, turbidity levels rose, and many fish and insects were killed. Therefore, slowly drawing down a reservoir before commencing dam removal can significantly reduce the impact of supersaturation on downstream species (American Rivers 2002). Finally, dam removal can cause aggradation of the downstream channel, resulting in increased flood stage, channel braiding, increased channel migration, bank erosion, and channel avulsion (Randle 2003).

Dam removal can be completed using several methods, such as explosives or mechanical equipment. However, the method used is usually dependent on the amount and type of sediment stored in the reservoir. The sediment can be left and moved downstream by the river after the dam is removed. Another method is to remove just a portion of the dam at a time, so that sediment is removed more slowly, minimizing downstream impacts. A third method is to draw down the reservoir and mechanically remove the sediment or stabilize the sediment in the upstream channel, and then remove the dam.

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Fish Passage Case Studies

Many dams throughout the world provide fish passage. The table in Appendix B lists the dams that were found during our research and documents the types of fish passage used at each dam. From these dams, several were chosen to be case studies in this document. The dams were generally chosen because of the height that the technology overcomes, the uniqueness of the technology, the possible relevance to projects in California, or because the passage facility was recently constructed. Dams with fish passage facilities to be constructed are also included. The aim was to include all the various methods used for fish passage at large dams. In addition, case studies of large dams that have been or soon will be removed were included. The case studies describe in detail the upstream and downstream technologies used at specific dam projects throughout the world. They provide a general overview of the project, the history of fish passage at the project, and the current upstream and downstream technologies being used. All dam heights listed refer to hydraulic height unless otherwise noted.

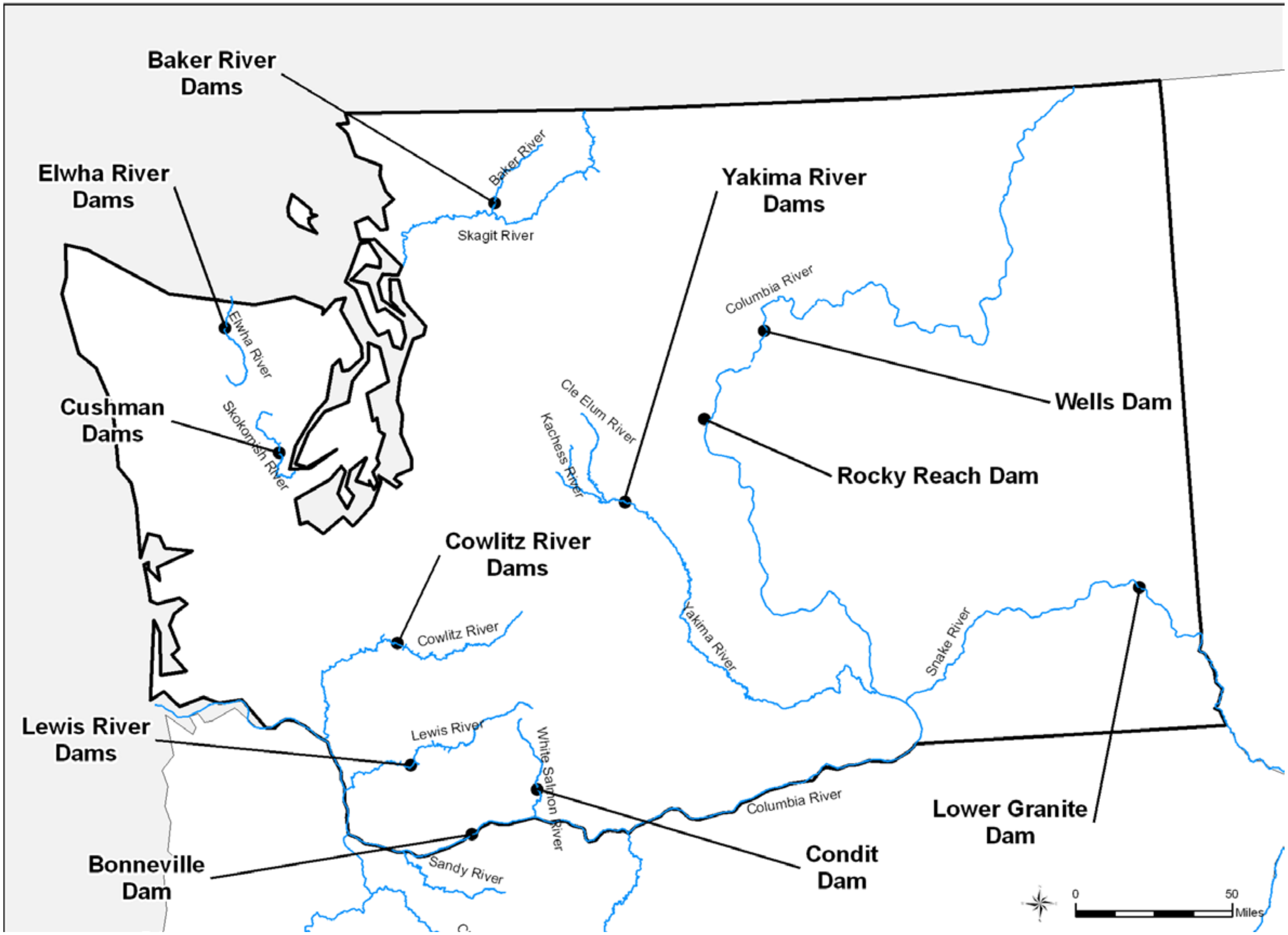

Figure 57: Case Studies in Washington State

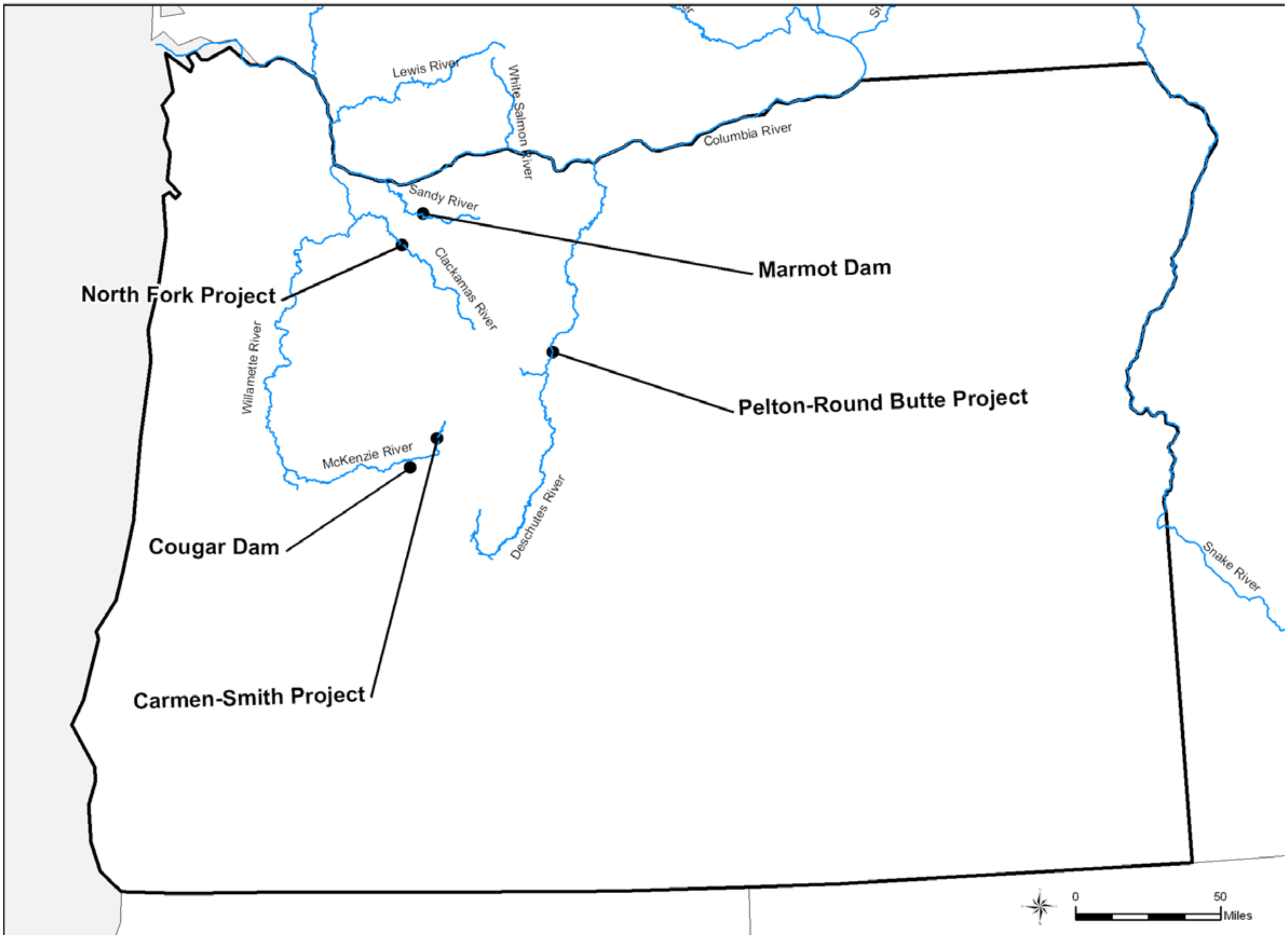

Figure 58: Case Studies in Oregon

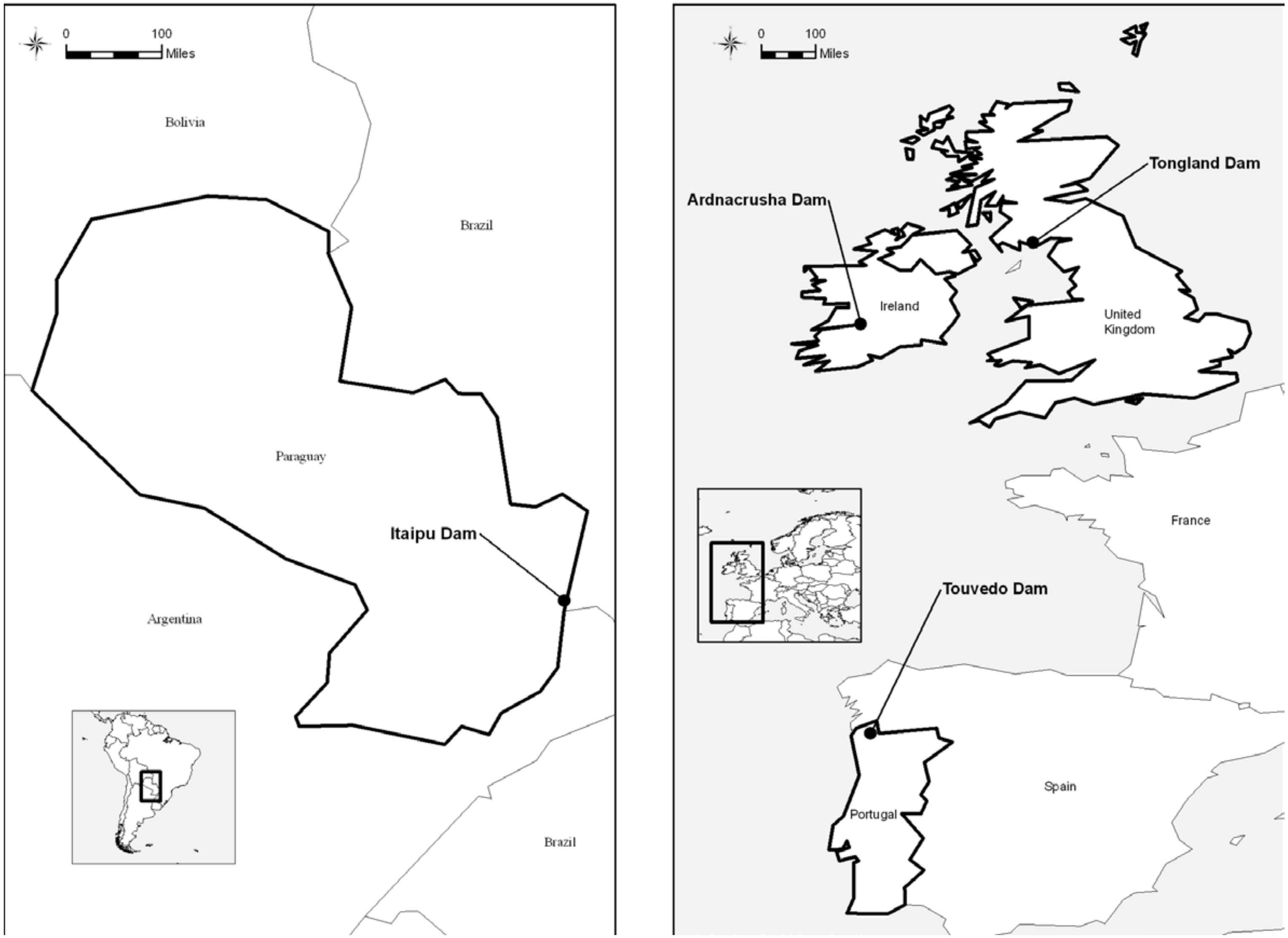

Figure 59: Case Studies Outside of the United States

Figure 60: Case Studies in California

Case Studies

United States — Washington

Baker River Hydroelectric Project

Location: Baker River, near the town of Concrete, Washington, roughly 80 miles northeast of Seattle. Lower Baker Dam is approximately one mile upstream of the Skagit River. Upper Baker Dam is approximately nine miles upstream of Lower Baker Dam.

Owner: Puget Sound Energy (PSE)

Dam Name: Lower Baker Dam **Hydraulic Height:** 277’ **Year Constructed:** 1925

Dam Name: Upper Baker Dam **Hydraulic Height:** 304’ **Year Constructed:** 1959

Target Species: Sockeye salmon, coho salmon, Chinook salmon, steelhead, bull trout, Dolly Varden, and sea-run cutthroat trout

Upstream Passage: Adult fish trap and haul

Downstream Passage: Floating surface collector with trap and haul

Description

The Baker River Hydroelectric Project (Project) is located on the Baker River, a tributary to the Skagit River in northwestern Washington (Figure 61). The Project is managed for hydropower generation, flood control, fisheries enhancement, and recreation. It is composed of two dams, Lower Baker Dam and Upper Baker Dam, each with its own powerhouse, generating up to 79 MW and 91 MW, respectively. Lower Baker Dam is a 550 foot long, 285 foot high, concrete gravity-arch dam with one generating unit. Upper Baker Dam is a 1,200 foot long, 312 foot high, concrete gravity dam with two generating units, located roughly nine miles upstream of Lower Baker Dam. Lake Shannon, approximately 7.5 miles long, is behind Lower Baker Dam. Baker Lake, approximately 9.5 long, is behind Upper Baker Dam. Figure 350 shows a map of Baker River and the two reservoirs. Both dams are operated similarly except Lower Baker Dam needs to generate power roughly 20 percent longer than Upper Baker Dam to avoid spill. This is due to higher inflows at Lower Baker Dam, a smaller reservoir (Lake Shannon), and lower hydraulic capacity.

The Project was operating on a 50-year federal operating license until its expiration in April 2006. It operated with an annual license until a new 50-year license was granted in October 2008 by the Federal Energy Regulatory Commission (FERC). The eight year relicensing process resulted in a 162 page settlement agreement signed by 24 parties. Roughly $360 million dollars will be spent to meet the new settlement agreement provisions, with over half of the cost related to fish improvements. Installation of new upstream and downstream fish passage facilities and construction of a new fish hatchery are part of the license. Also included as part of the license, PSE proposes to construct a new auxilary powerhouse at Lower Baker Dam, adjacent to the existing powerhouse. This new powerhouse will improve the ability to control outflows which will improve the downstream conditions for fish. Two new generating units are planned to be installed with a total capacity of 30 MW. In addition the license requires PSE, as directed by the USACE, to annually provide 16,000 acre-feet of flood storage between October 15 and March 1 and up to an additional 58,000 acre-feet from September 1 to April 15 at Upper Baker Dam. If directed by the USACE, PSE must also annually provide up to 29,000 acre-feet of flood storage from October 1 to March 1 at Lower Baker Dam. (FERC 2008)

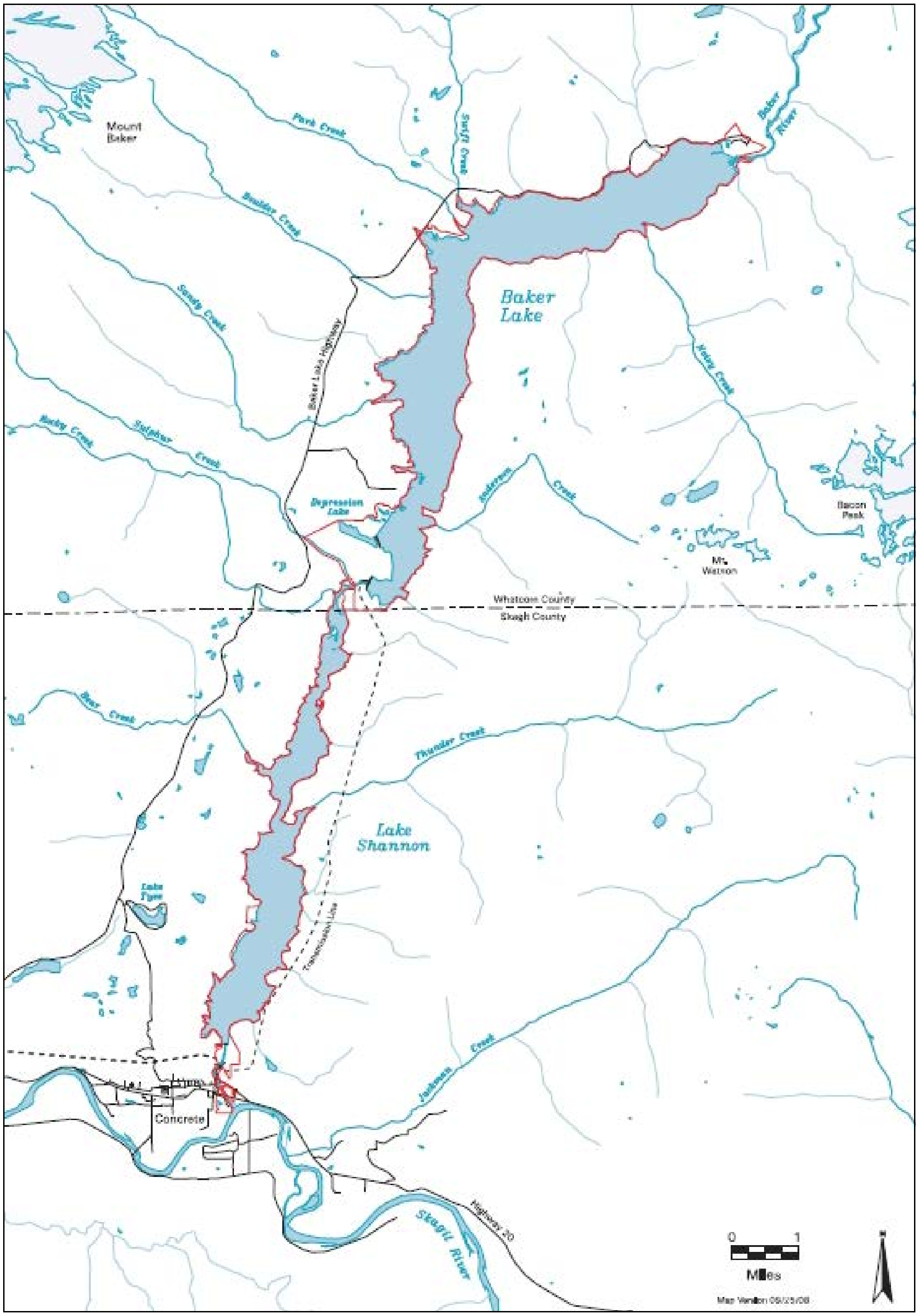

Figure 61. Map of Baker River and Reservoirs (courtesy of PSE)

Fish Passage History

Historically, the Baker River has supported seven species of salmonids, which are now collected at the adult fish trap downstream of Lower Baker Dam and transported upstream of both dams. The seven species collected are: sockeye salmon, coho salmon, Chinook salmon, steelhead, native char (bull trout and Dolly Varden), and sea-run cutthroat trout. Chum salmon and pink salmon, two species not historically present in the Baker River system, have also been collected and transported to the reservoirs (Feldmann 2010). The two most abundant species are coho and sockeye salmon, which on average comprise 94% of total trap return numbers (PSE 2002).

Since 1955, a program for downstream passage of anadromous salmonids has been in effect. A trap and haul program for upstream migration between the Skagit River and the Project reservoirs has been implemented since 1926.

For downstream passage, two Floating Surface Collectors (FSC) called “fish attraction barges” were built during the construction of Upper Baker Dam. Initial studies, done in the 1960’s, overestimated survival and passage efficiency of salmon through the FSC system. In the late 1980s, guide nets were installed to prevent fish from entering the turbines and direct them into the FSC. Eventually the FSC reached its maximum lifespan and was due for a replacement. In 2004, PSE committed $50 million dollars to design and construct a new FSC and guide net system at Upper Baker Dam. Major components of the new system were completed in October 2007 and the system was totally functional for the spring 2008 salmon run. In 2008, 235,000 sockeye juvenile salmon were collected, transported, and released into the Skagit River. The new FSC is considered the prototype downstream salmon passage facility for deep water reservoirs (PSE 2009b).

In 2010, PSE completed a new fish hatchery and “spawning beach” near Upper Baker Dam (Figure

Figure 62: Baker River hatchery spawning beach (CA Dept. of Water Resources)

62). A news release from the PSE website provides a description of the "spawning beach":

> In addition to building a new, larger fish hatchery on the Baker River, PSE is upgrading its nearby sockeye "spawning beach." The man-made, 20-year-old beach – essentially a series of large, gravel-bottom pools with spring-fed water circulating through them – provides a controlled, predator-free environment for adult sockeye to lay and fertilize their eggs.
>
> The new hatchery and renovated spawning beach are designed to produce five times more fish eggs and hatched fry – up to 11 million, initially – than PSE's original, 1970s-era fish-culturing facility could generate. (PSE 2010a)

Upstream Passage

In 2010, PSE completed construction of a new adult fish trap in the same location as the original trap about 0.5 miles upstream from the Skagit River (Figures 63 and 64). It cost approximately $25M and replaces the original trap that was built in 1958. Upstream migrating fish are blocked by the barrier dam and are attracted into the entrance pool. They then move through two holding ponds to get to the brail pond. From the brail pond fish enter a water-filled tower, 7 feet in diameter and 60 feet tall, which raises fish from the river level to the facilities on the river bank (Figure 65). Fish exit at the top of the lock by means of a false weir (Figure 66). There is a programmable control system for sorting fish by species and separating them into six holding pools (Figure 67). From the holding pools, fish are transferred to a fish box on a flatbed truck via automated systems with minimal handling of fish (PSE 2010b).

Figure 63. Adult fish trap facility, below Lower Baker Dam (Courtesy of PSE)

Holding pond #1

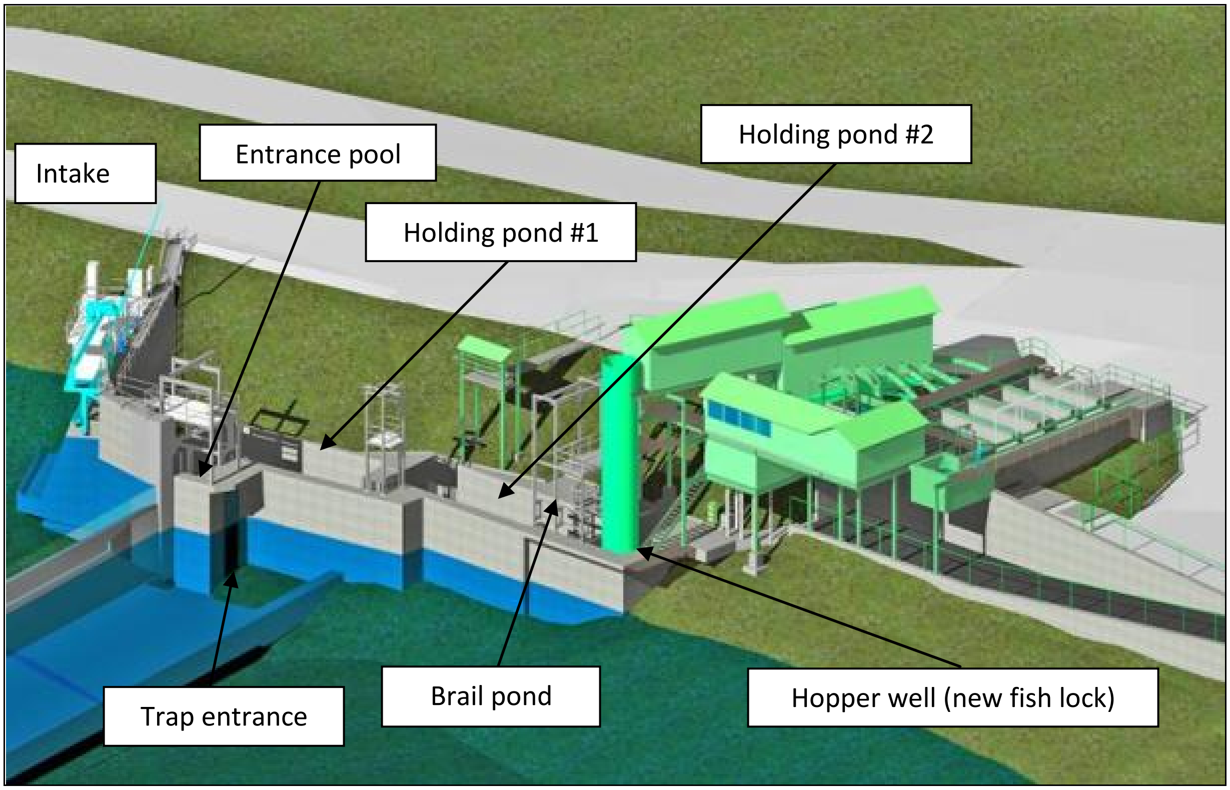

Figure 64. Isometric view of the adult fish trap facility (courtesy of PSE)

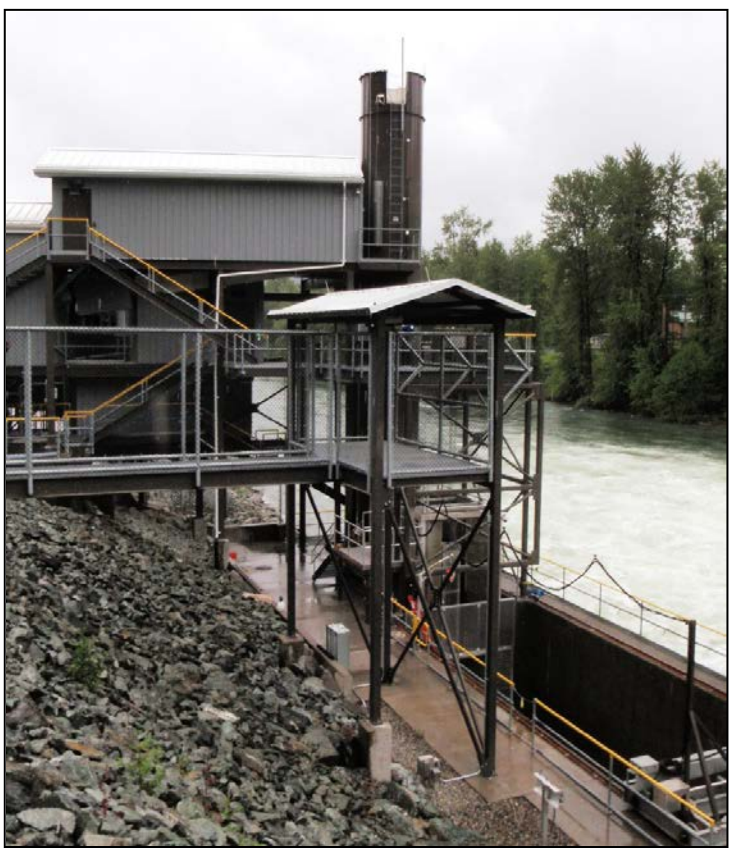

Figure 65: Holding pond #2, brail pond, and fish lock (CA Dept. of Water Resources)

Figure 66: False weir at top of fish lock (CA Dept. of Water Resources)

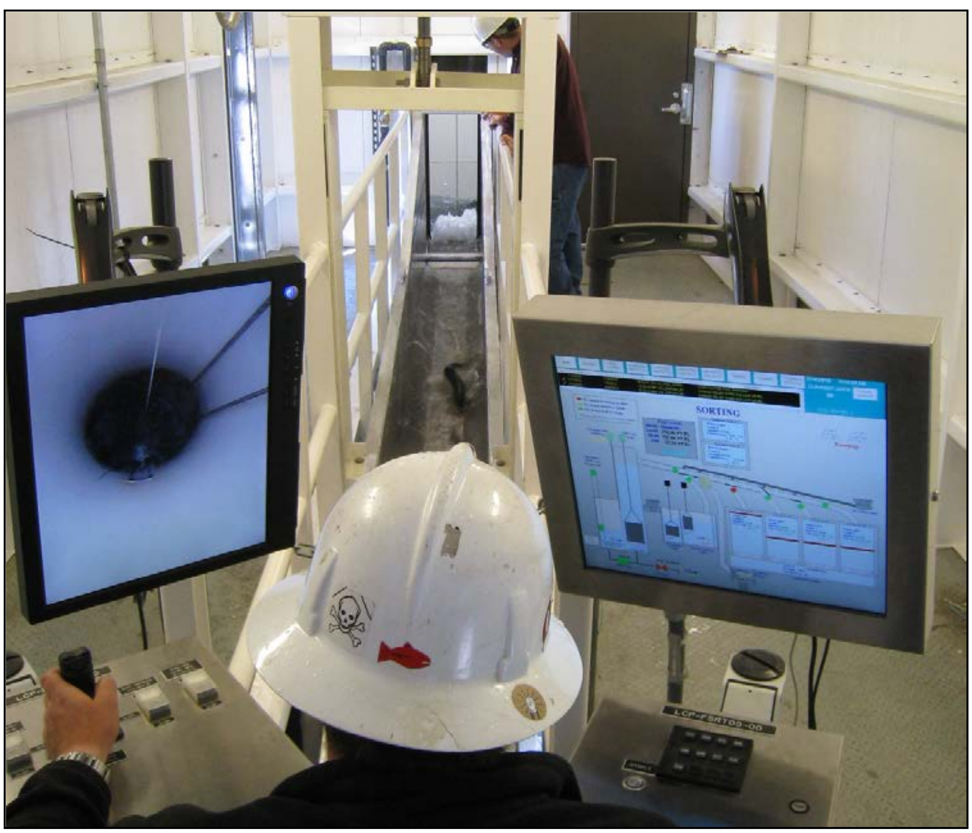

Figure 67: False weir in operation - fish identification and sorting (Courtesy of PSE)

Downstream Passage

The Floating Surface Collector (FSC) behind Upper Baker Dam is the primary facility for downstream passage of outmigrating juvenile salmonids from Baker Lake to the Skagit River. Figures 68 and 69 show the completed FSC in operation and Figure 70 shows an isometric view. A May 12, 2009 news release from PSE describes the system and its success:

> In its first year of operation in 2008, the $50 million apparatus induced the highest outmigration rate on record for juvenile Baker River sockeye. An estimated 90 percent to 95 percent of the watershed's sea-bound sockeye were safely guided into the collector for water-truck transport around PSE's two North Cascades dams. And just last week, the new collector twice smashed the old record for the number of young salmon gathered in a single day. On Saturday, the facility collected 60,629 juvenile sockeye, followed by 58,275 on Sunday [*Since then, a new one-day record of an estimated 94,000 juveniles has been established – as of May 23, 2012*]. The old one-day record, set in 2006 by PSE's first-generation floating surface collector, was 28,294.
>
> The National Marine Fisheries Service has called PSE's new system a model for other high-reservoir dam operators. Representatives from some two dozen domestic and foreign utilities already have toured PSE's Baker River operation, with several of those utilities either exploring or actively pursuing fish-migration systems based on PSE's so-called "gulper."
>
> The new floating surface collector is a one-of-a-kind, 130-foot-by-60-foot barge equipped with a series of submerged screens, water pumps, fish-holding chambers, a fish-evaluation station, equipment-control rooms, and a fish-loading facility. The guide nets, extending from each side of the collector to the opposing lake shores and from the lake's surface to its bottom, form an impassible netting funnel to lead small migrating fish to the

Figure 68. Upper Baker Dam FSC (courtesy of PSE)

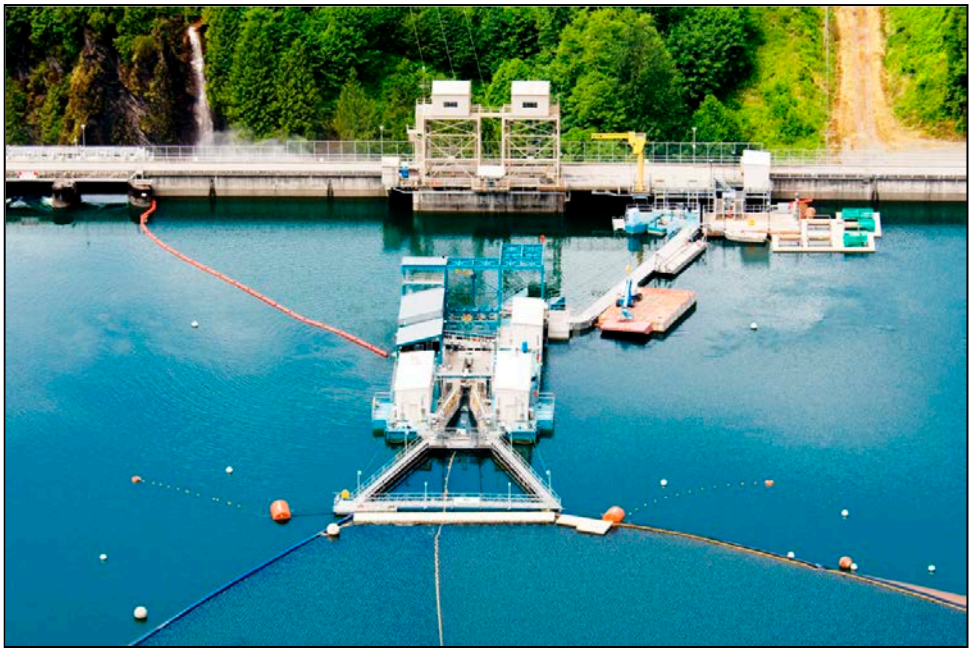

Figure 69: Upper Baker Dam FSC (Courtesy of PSE)

Figure 70: Isometric view of Upper Baker FSC and net transition structure (Courtesy of PSE)

In the spring of 2010, more than 520,000 fingerling salmon, mostly sockeye, were collected by the FSC and transported downstream (PSE 2010a).

Cary Feldmann, Manager of Resource Sciences at Puget Sound Energy, provided more details on the downstream passage facilities:

> The facility features conventional vee-screens within a floating channel, with flow induced by pumps. The FSC provides 500 cfs of attraction flow, which is nearly four times the 132 cfs provided by the previous Upper Baker collector (called the "gulper"), and meets the NMFS screening criterion of 0.4 ft/sec approach velocity. The facility was designed with a 1,000-cfs pumping capacity (20% of the Upper Baker generation capacity) to test the difference in performance of the two flows. The design is also expandable, should a study demonstrate that a higher attraction flow significantly improves collection efficiencies. The FSC integrates a fish trap with sampling, handling, and transport facilities. Flotation tanks and buoyancy control are similar to that of a dry-dock, enabling the FSC to be raised to expose submerged equipment for maintenance during the non-operating season.
>
> The net transition structure (NTS), attached to the upstream end of the FSC and the downstream end of the guide net, is a narrowing channel with inclined floor that provides a gradual physical and hydraulic transition from the open lake and the guide net to the FSC. It extends the entrance of the FSC to include the range of migration depths for most migrating fish (0-50 feet). The NTS modifies initial approach conditions, removing flow discontinuities, and controlling acceleration and velocity leading to the primary screens of the FSC. The NTS walls and floor are supported by galvanized steel truss frames lined with sheets of high density polyethylene (HDPE) plastic. Two trusses span the top walls to provide rigidity. The NTS is detached from the FSC during the non-operation season, when the FSC is raised for maintenance activities.

> The guide net, attached to the upstream end of the NTS and extending upstream into the forebay from the surface to the bottom of the reservoir and from shore to shore, creates a "soft vee-screen" barrier to guide fish to the NTS and FSC, and to prevent entrainment into the penstocks [Figure 5]. The net's small mesh acts not only as barrier to fish; but its angled approach and the water circulation pattern induced in the reservoir by the FSC pumps and turbine generation also provide guidance by inducing a sweeping current parallel to the net and along the surface. The upper 30 feet of the net is 3/32-inch nylon mesh, and the remainder, to the bottom of the lake, is quarter-inch nylon mesh. The net has an automated float line submergence capability for both boat passage and spill during flood operations. (Feldmann 2010)

Figures 71 through 73 *(these are PDFs and need to be inserted)* are preliminary drawings provided by PSE that show further details of the Upper Baker Dam FSC facilities. Figure 71 shows a plan view of the General Arrangement of the Operating Deck. Figure 72 displays the General Arrangement with Hydraulic Data in a profile view. Figure 73 provides a Screened Water Flow Diagram for the FSC.

After passing the net transition structure, fish are swept past the primary fish screens (Figure 74) as the channel narrows from 16 feet to 2.85 feet at the entrance to the secondary fish screens (See Table 350 for FSC attributes). At an FSC entrance flow of 500 cfs, the primary fish screens remove 365 cfs and 135 cfs enters the secondary fish screens. The primary screens are cleaned by a horizontal brush system that moves vertically. The secondary screens (Figure 75) remove 132 cfs as the channel narrows to 1 foot wide. The secondary screens are cleaned by a water backwash system.

Figure 74: Upper Baker Dam FSC primary fish screens (NOAA Fisheries)

Table 5: Floating Surface Collector Attributes (Courtesy of PSE)

FSC Design Specifications *(length - 130', width - 60')*					
Location	**Flow (cfs)**	**Width (ft)**	**Depth (ft)**	**Velocity (fps)**	**Acceleration (fps/ft)**
NTS Entrance	500	75	50	0.13	0.00
Primaries Entrance	500	16	15.42	2.03	0.00
Secondaries Entrance	135	2.85	7.33	6.45	0.20
Capture Area	93.0	2.20	5.03	8.40	0.19
Secondaries Exit	3.0	1.00	0.82	3.70	-0.08
Trap Entrance	3.0	1.0	0.65	4.60	0.09

Figure 75: Upper Baker Dam FSC secondary fish screens - looking upstream (CA Dept. of Water Resources)

As fish move through the FSC past the capture point in the secondary screen channel, a PIT tag detector is used to record tagged fish. Special gates are used to move fish with tags to a specific raceway. All fish that are collected in the FSC are held in raceways until they are ready to be evaluated. Crowders move fish from the raceways to a hopper. The hopper, containing water and fish, is lifted by a crane and moved by tram rail to the evaluation station. Next, crowders move fish into a dewatering channel and into a pre-anesthesia raceway to reduce stress. Small groups of fish are netted and are placed into a higher concentration of anesthesia to induce them to sleep. The fish can be evaluated for species type, weight, length, time of capture, and markings. Juveniles are then moved into special holding tanks for use in studies or into transport tanks for recovery (PSE 2008).

The transport tanks, self-contained vessels that have oxygen diffusers and aerators, are moved to the docking station. A barge transfers the transport tanks to loading facilities on the dam (Figure 76). The transport tanks are then loaded onto flat bed trucks or trailers for transport to stress relief ponds just downstream from the adult collection facility. Since research has shown fish are likely to have a better chance of survival if they have de-stressed first, fish are held for two days in stress relief ponds, before being released to the river (PSE 2008).

As of May 2012, construction on a new FSC for Lake Shannon is expected to be completed in October

2012 (Figures 77 - 79). This FSC will be similar to the one in Upper Baker Lake, but will be much farther from the dam and thus two reservoir transport vessels are being constructed to move the fish from the ies for juvenile

Figure 76: Upper Baker Dam FSC fish barge and tank (right) – photo taken from dam (CA Dept. of Water Resources)

Figure 77: New FSC for Lake Shannon - Upstream side showing primary fish screens (CA Dept. of Water Resources)

Figure 78: New FSC for Lake Shannon – Side view showing water exit ports (CA Dept. of Water Resources)

Figure 79: Net transition structure framework for Lake Shannon FSC (CA Dept. of Water Resources)

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Cowlitz River and Cowlitz Falls Projects

Location: Cowlitz River, Washington. Mayfield Dam is 52 river miles upstream of the Columbia River and 13 miles east of the city of Toledo.

Owner: The City of Tacoma for the Cowlitz River Project and Lewis County Public Utility District for the Cowlitz Falls Project.

Dam Name: Mayfield **Hydraulic Height:** 230' **Year Constructed:** 1963

Dam Name: Mossyrock **Hydraulic Height:** 366' **Year Constructed:** 1968

Dam Name: Cowlitz Falls **Hydraulic Height:** 120' **Year Constructed:** 1993

Target Species: Spring-run Chinook salmon, fall-run Chinook salmon, coastal cutthroat trout, coho salmon, and steelhead

Upstream Passage Summary: Trap-and-Haul from below Mayfield Dam to release sites on the Cowlitz, Tilton, and Cispus Rivers.

Downstream Passage Summary: Fish from upstream of the three dams are collected at Cowlitz Falls Dam and trucked downstream of all the dams. Fish below Cowlitz Falls Dam are collected at two louvered intake facilities just upstream of Mayfield Dam and piped through the dam to the river downstream.

Project Description

The hydropower portion of the Cowlitz River Project consists of Mayfield and Mossyrock dams, which are the two largest electricity generating facilities owned and operated by the City of Tacoma (Tacoma Power). The Cowlitz Falls Project is owned and operated by the Lewis County Public Utility District. We discuss these two projects together because they cooperate with each other regarding fish passage.

On August 10, 2000, Tacoma Power, state, federal, and other government agencies, tribes, and conservation groups came to a settlement agreement that resolved all issues, to the satisfaction of the parties, associated with issuance of a new license for the Cowlitz River Project (Tacoma Power 2000). The Federal Energy Regulatory Commission (FERC) approved the settlement and issued a new license for the Cowlitz River Project in 2002.

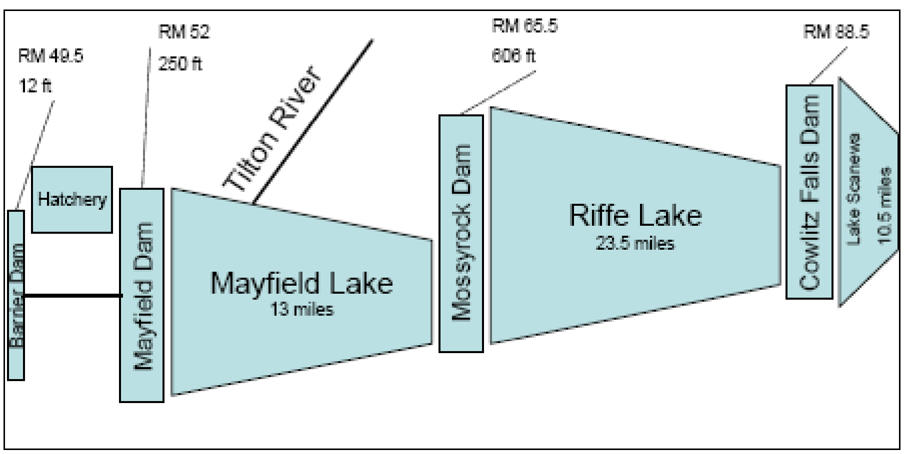

Figure 80: Schematic of Cowlitz and Cowlitz Falls Projects

The Cowlitz River Project generates power, provides flood protection and water supply, and recreation opportunities. It includes two large dams, Mayfield and Mossyrock, as well as the Cowlitz Salmon Hatchery and its small dam, Barrier Dam, and the Cowlitz Trout Hatchery (Figure 80).

Mayfield Dam (Figure 81), the lowermost major dam on the river, stands 250 feet above bedrock and was completed in 1963 at a cost of $44.5 million dollars. It is a concrete arch and gravity dam, which holds back 134,000 acre-foot, 13-mile-long Mayfield Lake. The dam has the capacity to release 203,000 cfs through the overflow spillways, and four penstocks provide water to the four 40.5 MW

Francis turbines for a total power generating capacity of 162 MW.

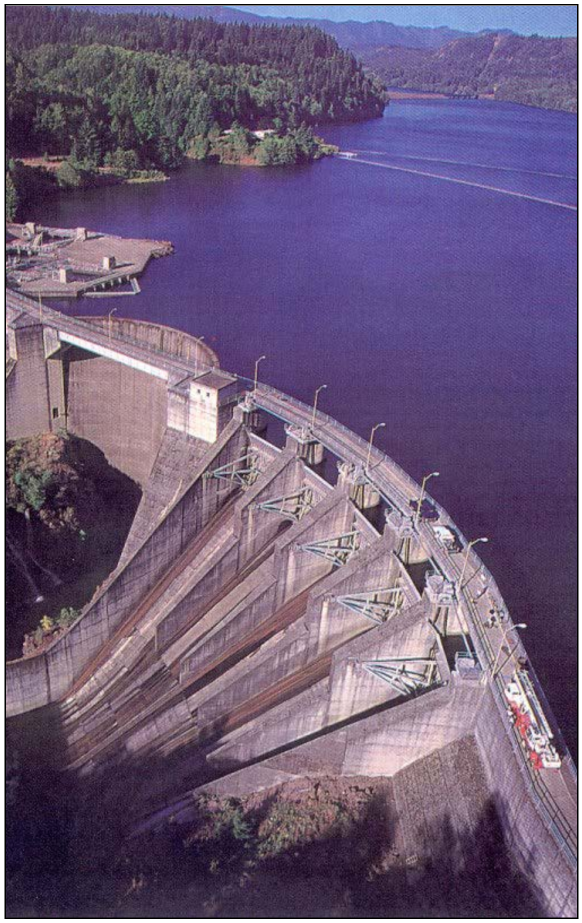

Figure 81: Mayfield Dam with Downstream Migrant Collection Facility at Upper Left (Photo Courtesy of the Mossyrock School District)

Mayfield Dam is operated in a run-of-river fashion, as outflows are controlled by releases from Mossyrock Dam upstream and inflows from the Tilton River and Winston Creek. If total reservoir inflows are greater than the capacity of the turbines, excess water passes over the spillways. Thus, the reservoir water surface remains at a very constant elevation, typically fluctuating less than 3 feet throughout the year. The maximum allowable elevation fluctuation is 10 feet (FERC 2002).

Mossyrock Dam (Figure 82), just upstream from Mayfield Lake, rises 606 feet from bedrock and is Washington's tallest dam. The concrete arch dam was completed in 1968 at a cost of $117.8 million dollars and backs up water to form Riffe Lake. The lake is 23 miles long and its volume is nearly 1.7 million acre-feet. Two penstocks route water to the two Francis turbines in the powerhouse at the base of the dam, which generate up to 300 MW of power. The dam has a third unused penstock for potential future expansion. The spillway at Mossyrock Dam has a capacity of 240,000 cfs.

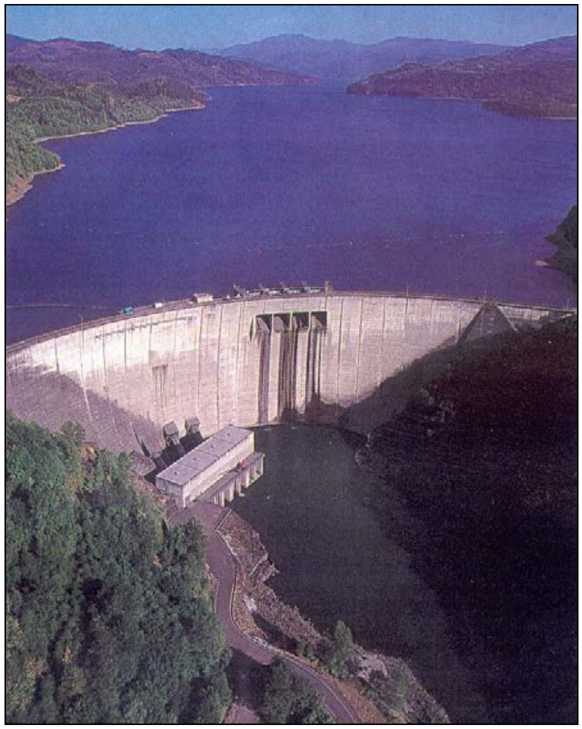

Figure 82: Mossyrock Dam (Photo Courtesy of the Mossyrock School District)

The Mossyrock Dam portion of the Project operates differently than Mayfield Dam in that it provides flood control and water supply. Thus, Riffe Lake fluctuates to a much greater extent. Typically, Riffe Lake is held at a low elevation between December 1 and January 31 to provide storage for winter flood flows, with the objective of keeping flows below 70,000 cfs at the downstream community of Castle Rock. From February 1 to June 1, Riffe Lake is allowed to fill in an attempt to have the reservoir at or near full pool for the summer recreation season. Typically, the reservoir slowly releases water throughout the summer, because minimum downstream flow requirements at Mayfield Dam are frequently higher than project inflows. Gradual drawdown to the winter pool level begins between Labor Day and October 1 (FERC 2002).

Tacoma Power built and maintains the Cowlitz Salmon Hatchery and Cowlitz Trout Hatchery as mitigation for impacts due to construction and operation of the Project and provides funding to the Washington Department of Fish and Wildlife for operational costs. Tacoma Power’s staff and trucks are used to transport fish upstream (NOAA Fisheries 2004).

Barrier Dam (Figure 83), 2.5 miles downstream of Mayfield Dam, was constructed in 1969 to direct migrating adult fish into a ladder that connects to the Cowlitz Salmon Hatchery. The salmon hatchery was completed in 1968 and produces nearly 13 million fish each year, including about 1.3 million spring-run Chinook, 5.0 million fall-run Chinook and 2.4 million coho (Tacoma Power 2010b).

Figure 83: Barrier Dam with Downstream Migrant Outfall Pipe (Photo Courtesy of Tacoma Power)

The Cowlitz Trout Hatchery was completed in 1967 and is located about 7.5 miles downstream of the salmon hatchery. There are no barriers in the Cowlitz River associated with the hatchery (NOAA Fisheries 2004). Fish voluntarily enter the hatchery from Blue Creek just upstream of its confluence with the Cowlitz River. The hatchery produces and releases about 1.5 million fish each year, including summer and winter steelhead, and sea-run cutthroat trout (Tacoma Power 2010c).

The Cowlitz Falls Project is located on the Cowlitz River immediately upstream of the Cowlitz River Project's Riffe Lake. The Lewis County Public Utility District (LCPUD) and the Bonneville Power Administration (BPA) cooperatively developed the Cowlitz Falls Project in the early 1990s. The LCPUD is owner of the project, while the BPA has purchased the annual energy output of the Cowlitz Falls Project under a long-term contract. In exchange for receiving the energy output, BPA pays all costs associated with its operation and maintenance. The LCPUD buys its power from BPA (LCPUD 2010).

Cowlitz Falls Dam (Figure 84), the only dam in the Cowlitz Falls Project, lies just downstream of the confluence of the Cispus and Cowlitz Rivers. The 140-foot-high concrete gravity dam holds back 11,000 acre-foot Lake Scanewa, which extends upstream into the Cowlitz and Cispus River valleys 10.5 miles and 1.5 miles, respectively (Tacoma Power 2008c).

Figure 84: Cowlitz Falls Dam with Fish Facility on Left Side of Photo (Photo Courtesy of Lewis County Public Utility District)

The powerhouse at Cowlitz Falls is of the overflow design (hydro-combine design), meaning the powerhouse and service spillway are integral parts of the dam, and part of the spillway discharges directly over the powerhouse (MWH and ENSR 2005). It is operated in a run-of-the-river mode, meaning that it does not provide flood control or water supply and reservoir water surface elevations vary little, with water entering and exiting the reservoir in less than 24 hours. It has two Kaplan turbines capable of producing up to 70 MW.

Fish Passage History

The Cowlitz River historically supported abundant runs of coho, spring- and fall-run Chinook salmon along with steelhead and sea-run cutthroat trout. Construction of the Cowlitz River Project effectively blocked volitional migration to about 80% of the historical spawning habitat for anadromous fish. Initially, Tacoma Power attempted to collect out-migrating smolts upstream of the Mossyrock Dam with Lake Merwin type traps. However, this trapping was unsuccessful and discontinued after 1973. This effectively eliminated anadromous fish production in the upper Cowlitz watershed until the 1996 construction of the run-of-the-river Cowlitz Falls Dam and its juvenile fish collection facility (Tacoma Power 2008c).

At the time of its construction, Mayfield Dam was equipped with both upstream and downstream fish passage facilities. The adult fish passage facilities were abandoned after a decision was made to stop passage into the upper basin and to use hatcheries instead (Barrier Dam was completed in 1969). However, many components of this facility still exist, including the 25-foot-high dam at the base of Mayfield Dam, lower fish ladder, trap, tramway track, and transfer building. When upstream passage was in operation, the small dam directed fish into a collection channel in the lower level of the powerhouse and a fish ladder directed fish into a 1,500-gallon hopper. Then fish were hauled to the top of a tramway on a railed carriage and discharged into the reservoir through a pipe. The downstream fish passage facility consisted of a series of vertical louvers constructed in a V-formation within the intake and a bypass channel that directed the fish to a secondary separator, where they were guided through the dam to a holding/counting facility and emptied into the river below the powerhouse through a pipe and chute (NOAA Fisheries 2004). The louver system for downstream passage is still functional and effective. It is used to sample fish populations stocked in Mayfield Lake and the Tilton River, and to collect downstream migrants originating in Mayfield drainages (NOAA Fisheries 2004).

From Article 2 of the Settlement Agreement (FERC 2002), Tacoma Power is tasked with improving downstream fish passage survival at Mayfield Dam to a level greater than or equal to 95% for anadromous stocks. Downstream fish passage survival rate, as used in License Article 2 and applied to Mayfield Dam, is the percentage of smolts entering the Mayfield Dam louver system that survive movement through the juvenile fish guidance and bypass facilities, plus those juveniles that pass safely through the project turbines or over the spillway (FERC 2002).

Due to its height, Mossyrock Dam was not equipped with upstream or downstream fish passage facilities. Past attempts to develop juvenile fish passage facilities in the reservoir were unsuccessful due to a combination of factors, including reservoir size, water temperature, and the limitations of collection technology available at that time. Riffe Lake is operated within a rule curve to provide winter flood control and instream flow releases below Mayfield Dam to protect fish habitat (NOAA Fisheries 2004). One reason that upstream passage was not attempted at Mossyrock Dam at the time of its construction was that the technical opinions of 1968 were that the low currents and thermal stratification in Riffe Lake would prevent natural upstream fish migration above the dam, thus volitional passage over Mossyrock Dam was not a viable option for migration (Tacoma Power 2006).

At the Cowlitz Salmon Hatchery, a trap and haul system was incorporated when constructed in 1968. The facility has been in continuous operation since July 11, 1968, and replaced the upstream passage facilities provided at Mayfield Dam from 1961 to 1968 (Tacoma Power 2006). The trap and haul system at the Cowlitz Trout Hatchery was begun at about the same time.

The NOAA Fisheries Biological Opinion (2004) states that Tacoma Power will continue to provide and maintain effective upstream fish passage at Barrier Dam, Mayfield Dam, and Mossyrock Dam through trap and haul facilities until they meet criteria (described below), at which point Tacoma Power will construct volitional upstream passage systems.

These criteria include:

- Development and implementation of a Disease Management Plan that defines an acceptable level of risk from *Ceratomyxa shasta (C. shasta)* and other diseases, and allows adult fish to be upstream of Barrier Dam (protects the hatchery).
- Determination that adult fish in Mayfield Lake are able to choose their tributary of origin and survive Mayfield Lake transit at rates established by NOAA Fisheries and the USFWS to be sufficient to achieve effective upstream passage through volitional facilities.
- Documentation of self-sustaining levels of any salmonid species originating in the Tilton River Basin and self-sustaining levels of either spring Chinook salmon or late winter steelhead above Mossyrock Dam. These stocks will be considered self-sustaining when, in at least 3 of 5 consecutive brood years

measured, and when a 5-year rolling average indicates:

a) The number of pre-spawners arriving at Barrier Dam exceeds an abundance level that indicates natural recruitment above Mayfield Dam has achieved self-sustaining levels, as determined by NOAA Fisheries in consultation with the Fisheries Technical Committee.

b) The productivity level, as measured at Barrier Dam or other Cowlitz River fish counting facilities by the recruit/pre-spawner ratio, exceeds 1.0.

Within 12 years of license issuance, and when data indicate the passage criteria will be met within 3 years or less, Tacoma Power will prepare preliminary fish passage facility designs and schedules for the construction of volitional upstream passage systems for the Project.

Upstream passage systems will include:

- Breaching Barrier Dam, unless NOAA Fisheries and the USFWS determine in consultation with the Fisheries Technical Committee that a ladder is more appropriate than breaching for effective upstream passage, and disabling the electrical field.

- A ladder with sorting facilities at Mayfield Dam, unless NOAA Fisheries and the USFWS determine that a tram with sorting facilities is more appropriate for effective upstream passage.

- An adult trap and haul facility at Mossyrock Dam to facilitate adult transit above Cowlitz Falls Dam, to be built before or concurrently with the upstream system at Mayfield Dam, unless NOAA Fisheries and the USFWS determine that a comparably priced tram is more appropriate than a trap and haul facility. The appropriateness of a tram facility will be based on whether 1) fish are able to migrate through Riffe Lake, and 2) adult passage facilities will be provided at Cowlitz Falls Dam.

If volitional passage criteria have not been met by the end of Year 12 of the new license, but have been met or will likely be met by Year 15 of the new license, for any salmonid species originating in the Tilton River Basin, Tacoma Power will prepare preliminary Mayfield Dam volitional fish passage facility designs and construction schedules. Upon meeting the criteria for construction of the upstream volitional passage systems, Tacoma Power will complete design and construction of agency approved upstream fish passage systems, with the systems made operational.

The construction of Cowlitz Falls Dam created an additional barrier to migratory fish. Shortly after construction was completed, Bonneville Power Authority in cooperation with Lewis County Public Utility District, Tacoma Power, and state and federal agencies constructed a downstream anadromous fish collection facility. The facility was completed in 1996 and collects outmigrating juvenile fish (spring-run Chinook salmon, coho salmon, and steelhead) that had reared in the upper basin after being outplanted from the hatchery as well as steelhead kelts. These fish are trucked to the Cowlitz Salmon Hatchery for release in the Cowlitz River below Mayfield Dam (NOAA Fisheries 2004).

Lewis County Public Utility District operates the fish collection facility (Figure 85), which was designed to collect fish at the surface of the two middle spillway bays. The surface collector design was taken from the effective hydro-combine facility at Wells Dam on the Columbia River. The two center spillways are each split by a pier that divides the spillway into two 22 foot wide bays. The bays hold baffle panels which have openings designed to provide surface attraction flows that smolts would follow (Figure 86). The system was originally designed to provide about 10% of the total project flow through the baffle panel openings. About 90% of this baffle panel flow would exit the baffle panel area via the induction slot and on into the turbines to be used for power generation, leaving 1% of the total project flow for the fish bypass system (Tacoma Power 2008c).

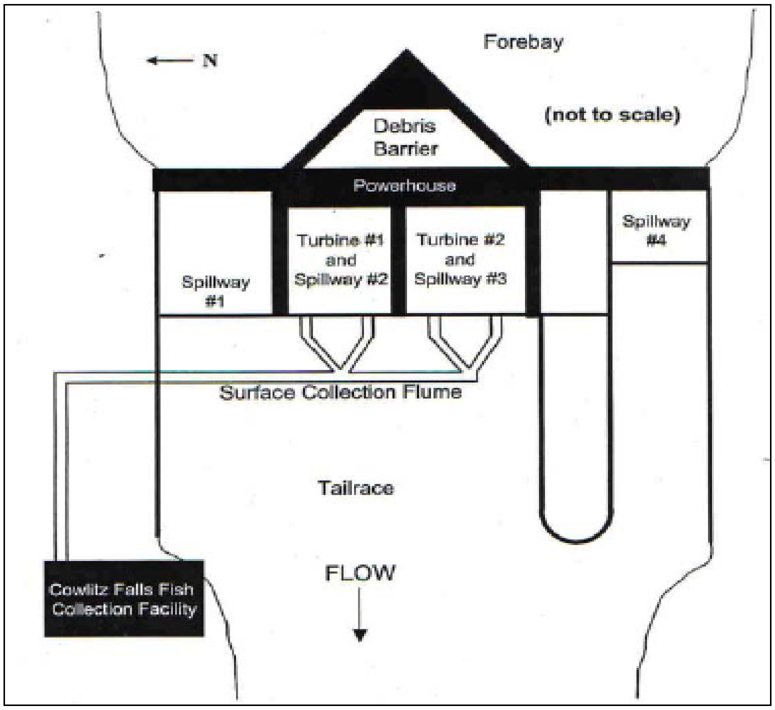

Figure 85: Cowlitz Falls Dam Facilities (Tacoma Power 2008c)

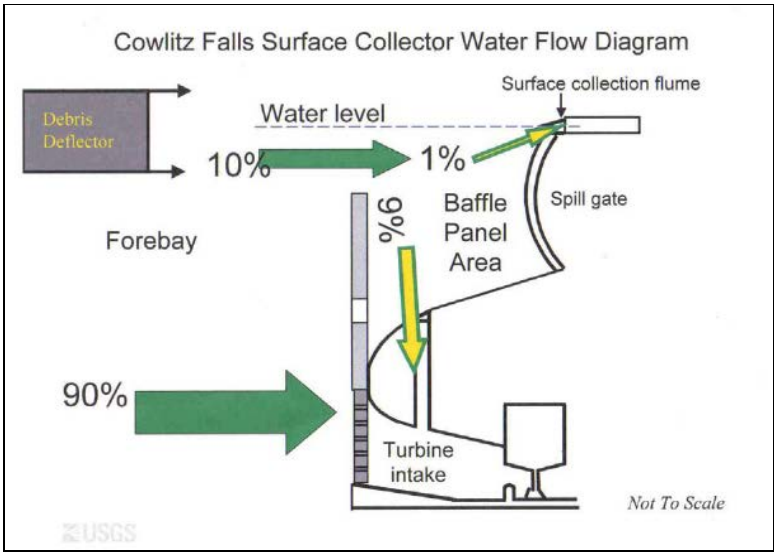

Figure 86: Section of Cowlitz Falls Surface Collector (Tacoma Power 2008c)

From the baffle panel area, fish pass through one of 4 small fish gates, which were cut in the much larger spillway gates (2 in each gate). From the gates, fish pass into the bypass flume system, four parallel two foot wide fish flumes that convey downstream migrants to the fish facility. The flumes operate with about four feet of water depth with the reservoir at full pool. Fish and water move down the four flumes, each with a capacity of 20 cfs, converging into a single flume with a capacity of approximately 80 cfs. Fish then encounter the dewatering facility and a fish separator, where fry, smolts and adults are separated from each other. Adults are returned to the river or held for sampling and truck loading for return to the upper watershed or downstream (in the case of steelhead kelts). Juvenile fish are sampled and moved to raceways to be held until being loaded onto trucks (MWH and ENSR 2005).

Bonneville Power Administration, Tacoma Power, and Lewis County Public Utility District have collaborated to evaluate and improve collection and downstream passage since the 1990s (see 1994 - 2007 chronology below). Tacoma Power contributions to fish passage research have stemmed from their need to satisfy downstream survival requirements identified in its Cowlitz Project relicensing Settlement Agreement. Studies by the U.S. Geological Survey and WDFW have detailed collection inefficiencies and thus have improved the understanding of fish passage at Cowlitz Falls (MWH and ENSR 2005).

> Chronological evaluation and improvement attempts of Cowlitz Falls Surface Collector Efficiency (Taken directly from Tacoma Power's 2008 Cowlitz Falls Workshop Background Paper)
>
> ***1994** — Cowlitz Falls Dam Completed. Cowlitz Falls Project Fisheries Management Plan: Anadromous Fish Reintroduction Program adopted*
> (Thompson, et al. 1992, GAIA 1994)
>
> ***1995** — Hydroacoustic evaluation of smolt travel at Cowlitz Falls Dam*
> See publication for details of results. (HTI 1996)

***1996** — Interim Facility, Initial Fish Collection Efficiency (FCE) estimates, HTI hydro-acoustics*
(HTI 1997, Serl and Morrill 1999a)

This was a partial season while the Cowlitz Falls Fish Facility (CFFF) under construction. The original configuration consisted of the ramped fish screen (RFS) in slot #3. Slots #1, #2 and #4 were operated with 4'wide by 36' deep slot configuration. Mark-recapture FCE measured at 50% for steelhead and 15% for coho. Collection ended prior to Chinook migration due to construction. Hydro-acoustic sampling suggested an average of 95.8% of all fish with net movement toward the turbine intakes were observed in the area immediately in front of the two center spillways. The CFFF was finished in the winter of 1996.

***1997** — Testing of original Ramped Fish Screen (RFS)*
(Serl and Morrill 1999b)

This was the first full spring-summer season of CFFF operation. The surface collector was configured the same manner as 1996. FCE results were 45% for steelhead, 21% for coho and 17% for spring [spring-run] Chinook sub-yearlings. A screen-in versus screen-out study of the RFS was conducted and more smolts were collected through the non-screened fish flumes than the RFS equipped fish flume. For steelhead, cutthroat and coho over 80% were collected in the nonscreened flume. Spring Chinook smolts were collected in similar numbers in slots with and without RFS. The RFS was determined to be ineffective and not used again. WDFW recommended not acquiring the three additional screens originally planned.

***1998** — Pilot radio telemetry with steelhead smolts, Turbine Fyke Net FCE testing*
(Adams et al. 1999, Serl and Morrill 1999b)

The dam was configured with all four baffle panels with the 4'wide by 36' deep slot. This was the first study with USGS-Columbia River Research Lab participation at Cowlitz Falls. This result suggests that steelhead smolts quickly travel to the dam but then delay passage at the dam. Steelhead that were not collected were found to be passing the turbines through the induction slots or were making upstream trips of several miles into the reservoir. FCE estimates were 32% for coho and 18% for spring Chinook and approximately 50% for steelhead.

***1999** — Strobe light study, Induced turbulence flow near zone w/ manifold. Forebay induced turbulent flow testing with coho.*
(Evans et al. 1999, Darland et al. 2001a, Serl and Morrill 2000a*)*

A strobe light system was tested to divert smolts from passing the induction slots. The results indicated that the strobe light increased induction slot passage when on. FCE estimates this year were 41% for steelhead, 17% for coho and 24% for spring Chinook. USGS conducted a near zone directed flow by pumping a surface jet of water at the fish flumes. This had no effect on fish collection. USGS also tested the directed flow system in the forebay and demonstrated that smolts could be moved with the directed flow system. FCE estimates at the CFFF were 41% for steelhead, 17% for coho and 24% for spring Chinook.

***2000** — Baffle Panel Testing, Forebay induced turbulent flow with Debris Barrier removed.*
(Darland et al. 2001b, Serl and Morrill 2000a)

The USGS, with US Army Corps of Engineers funding, tested directed flow in the forebay with two mixer configurations and the debris barrier removed. Positive results indicated that directed flow increased collection by 17% and 34% with the two configurations. FCE estimates were 65% for steelhead, 45% for coho and 24% for spring Chinook.

***2001** — Baffle Panels reconfiguration to "C"-horizontal, Rounded Flume Entrance tested*
(Farley et al. 2002, Hausmann, et al. 2001, Normandeau Associates, Inc.2001, Serl and Morrill 2000b)

After flow velocity profile testing, USGS suggested reconfiguring baffle panels to a "C" horizontal configuration that opened the top entrance to 22' wide and reduced the vortex that developed in the power bays. Radio telemetry demonstrated that the rejection that previously occurred at the 4' wide baffle panel openings was eliminated and >90% of steelhead smolts were detected within 1 meter of the flume openings. A small rounded flume entrance was constructed by Tacoma Power. Side by side sampling indicated that 80-90% of the smolts preferred the standard opening configuration. The rounded flume entrance was first painted a light gray color. When painted dark green, the proportion of smolts using this entrance doubled, but was still low. FCE estimates were 58% for steelhead, 42% for coho and 23% for spring Chinook. Normandeau and Associates, Inc. was contracted to conduct a turbine survival study by LCPUD. Survival rates of 97.3% and 97.6% were calculated for the one-hour and the 48-hour survival tests, respectively.

***2002** — 8' W x 2' D flume box tested with 40 cfs, induced turbulent flow*
(Serl and Morrill 2002, Meeting summary 2002)

Because most steelhead smolts were detected near the fish flume entrances, but delayed entering or rejected entering, we speculated that the 2' wide entrance was too narrow and began research to determine the necessary width required for effective entrance. A plywood and angle iron box with an 8' wide entrance was attached to one flume and about 40 cfs were passed through the box. The 8' opening was found to pass fish with little rejection, but the 2' entrance was still rejected. Passing 40 cfs through one gate with or without the box was found to be more effective at entraining fish than the standard 20 cfs opening. FCE estimates this year were 56% for steelhead, 33% for coho and 22% for spring Chinook. Tacoma Power convened a meeting to explore methods to meet the downstream survival goals identified in the Settlement Agreement. "The consensus from the brainstorming meeting with agency and consultants on January 31, 2002 at the Mayfield Office is that a full exclusionary system at the upper end of Riffe Lake is necessary for the first attempt to achieve the 95% survival goal."

***2003** — High discharge Wide flume entrance box, High Velocity Orifice (Tacoma)*
(Perry et al. 2004, Serl and Morrill 2003)

We tested collection with 40 cfs through one flume per turbine, with and without a wide entrance box compared to the standard configuration. Although the results indicate that operating the flumes at 40 cfs will improve attraction and entrainment into the flume entrances, problems remain with fish guidance, attractions and collection. FCE was measured at 68% for steelhead, 43% for coho and 13% for spring Chinook this year.

***2004** — Double Flume Box 40cfs vs 60 cfs, Lake Scanewa Merwin Trapping*
(Serl and Morrill 2004*)*

We further tested a wide opening with additional discharge created by expanding the box to cover both flumes to pull about 60 cfs though on opening. FCE this year was 48% for steelhead, 42% for coho and 14% for spring Chinook. Two Lake Merwin type traps, with 185 foot long, 30 foot deep lead nets, were fished in Lake Scanewa by WDFW [Washington Department of Fish and Wildlife] staff with funding from Tacoma, starting in late June, captured about 6.1% of the migrating Chinook.

***2005** — Turbine Fyke Net FCE testing, Lake Scanewa Merwin Trapping*
(Serl and Morrill 2005)

Cowlitz Falls Dam was fished in the “C” horizontal configuration with no other changes this year. Two Merwin traps fished in Lake Scanewa to add supplemental collection to our spring Chinook collection effort. This added an additional 8% collection to the 12% at the dam for a total FCE of 20% spring Chinook. FCE for steelhead was 42% and 36% for coho.

***2006** — First year of testing Tacoma Fish Screen*
(Kock et al. 2006, Serl and Morrill 2006)

The surface collector was configured so that a newly designed Tacoma Fish Screen (TFS) was the only surface collection route and the baffle panels on the other turbine were blocked. FCE estimates this year were 47% for steelhead, 26% for coho and 31% for spring Chinook. The TFS results for 2006 indicated that collection was reduced for steelhead and coho, but improved for Chinook. Didson acoustic camera footage indicated that there was a high rate of rejection within the screen. It was hypothesized that the steelhead and coho collection were reduced because of the decrease in surface attraction flow. The coho FCE estimates were 18.9% during two turbine operation and 52.1% during one turbine operation. In early May, smolts were noticed in the power bay and collection there began. About 10% of the smolts collected were collected on the turbine with the blocked up baffle panels, apparently by traveling up the induction slots.

***2007** — Second year of testing Tacoma Fish Screen with flow modifications and entrance trap.*
(Lietdke et al. 2007, Serl and Morrill 2008)

> A heart type trap entrance was added to the TFS in an attempt to decrease rejection of the screen. Adjustable flow control panels were added to the TFS and the position was changed to improve hydraulic conditions within the screen. FCE estimates this year were 42% for steelhead, 36% for coho and 20% for spring Chinook. Overall, FCE was lower than in 2006, except for coho. The improvement in coho FCE was likely due to the much lower than normal flows in 2007. Screen rejection was still a problem and discovery efficiency for Chinook was very low.

As seen in the chronology, the collection system at Cowlitz Falls Dam does not collect all of the downstream migrating salmonids. The effectiveness of the system has been documented every year since 1996. Annual collection efficiencies (from 1996 – 2007) have ranged from 41 – 68% for late winter steelhead, 15 – 45% for coho, and 12 – 31% for sub-yearling spring-run Chinook.

From Article 1 of the Settlement Agreement (FERC 2002), Tacoma Power will determine proposed facilities and measures most likely to achieve the goal of 95% fish passage survival. Fish passage survival, as used in License Article 1 and applied to Cowlitz Falls Dam, Riffe Lake, and Mossyrock Dam, means the percentage of smolts entering the upstream end of Scanewa reservoir, and adjusted for natural mortality, that are collected at Cowlitz Falls Dam and Riffe Lake and Mossyrock Dam, that are transported downstream to the stress relief ponds, and subsequently leave the stress relief ponds at Barrier Dam as healthy migrants.

Current Fish Passage

Tacoma Power uses a collection and transport strategy to move wild and hatchery salmon and steelhead past the three dams and reservoirs. Upstream migrating adult fish are collected at the Cowlitz Salmon Hatchery and Cowlitz Trout Hatchery downstream of Mayfield Dam and sorted by species and destination. Fish that were born at the hatchery are kept at the hatchery to produce the next generation of salmon or hauled upstream. Tacoma Power transports wild salmon by truck to sites on

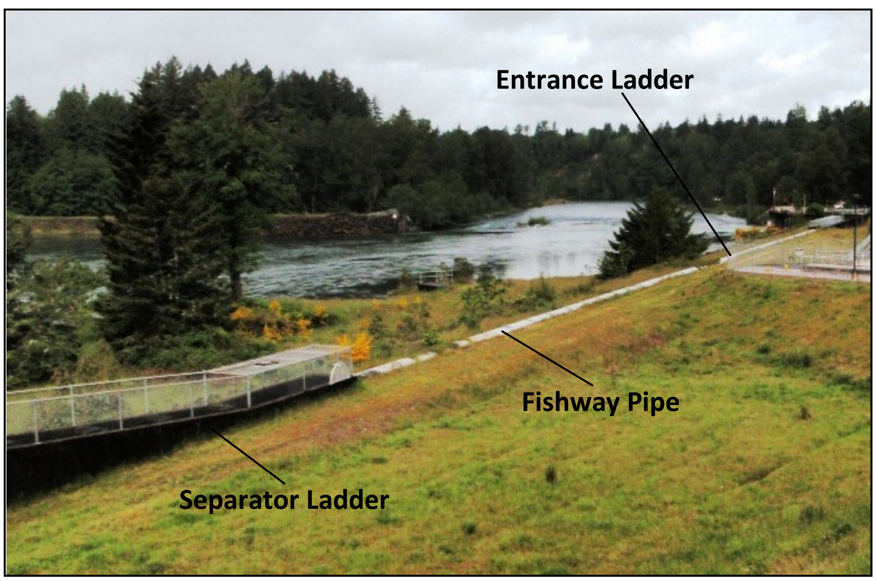

Figure 87: Cowlitz Salmon Hatchery entrance ladder, fishway pipe, and separator ladder (CA Dept. of Water Resources)

the Tilton, Cowlitz, and Cispus rivers to continue their spawning journey (Tacoma Power 2010b).

Downstream migrants upstream of the all the project dams are collected at Cowlitz Falls Dam and transported to holding ponds at the Cowlitz Salmon Hatchery, then released into the Cowlitz River just below Barrier Dam. As mentioned in the fish passage history section, downstream migrants in Mayfield Lake are collected via a series of vertical louvers constructed in a V-formation within the intake. A bypass channel then directs the fish to a secondary separator, where they were guided through the dam to a holding and counting facility, and then emptied into the river at the powerhouse tailrace through a pipe and chute (NOAA Fisheries 2004).

Upstream Passage

The Cowlitz Salmon Hatchery and the Cowlitz Trout Hatchery are the starting points for the collection and transport system. Most of the description of the upstream passage components is taken from the Tacoma Power Trap and Haul Plan 2006.

The upstream fish passage facilities at the Cowlitz Salmon Hatchery consist of a physical velocity barrier across the Cowlitz River, a ladder fishway to get the fish up to the hatchery, an adult fish holding and handling area, and a truck transportation area.

The Barrier Dam (Figure 83) is a velocity barrier, effectively preventing fish from migrating further upstream. This barrier directs the adult fish into a fishway entrance on the north side of the river. There are right and left bank entrances to the fish ladder and an under-dam transport channel connecting the two ladder entrances. Neither the transport channel nor left bank entrance are in use because of design problems with the attraction flow. There is also an electrical field at the Barrier Dam to aid in blocking fish (NOAA Fisheries 2004).

Figure 88: Cowlitz Salmon Hatchery separator ladder (CA Dept. of Water Resources)

There are three segments to the fish ladder: the 250-foot-long entrance ladder, the 450-foot-long fishway pipe, and the 225-foot-long separator ladder (Figures 87 and 88), which raises fish to the height of the holding pool. The ladders are of the half-Ice Harbor configuration and are approximately 5 feet wide with 2-foot-wide weirs. The ladders and fishway pipe are designed for 22 cfs and auxiliary river water is added at the lower end of the entrance ladder to increase the attraction flow to 200 cfs, which is 10% of the minimum flow established for the Cowlitz River below Mayfield Dam and 3% of the average annual flow of the Cowlitz River below Mayfield Dam. A minimal amount of additional hatchery raceway drain water is added to the ladder flow to entice the fish to climb the fish ladder. At the top of the separator ladder, fish jump over a finger weir and into a holding pool (Figure 89). The finger weir has curved upstream facing “fingers” attached to the top of it which prevent fish from moving back downstream until they are hand sorted.

To begin the sorting process, a crowder is lowered into the holding pool, which then moves forward and lifts, reducing the available area and a false weir begins flowing, encouraging fish to jump over the weir and into a box (Figures 90 and 91). In the box, the fish are given a low voltage shock for 1.5 minutes to make them immobile. The shock takes 5 to 6 minutes to wear off. The shocked fish then are shunted down a slide to a sorting table (Figure 92).

Fiberglass tubes transport the fish by gravity into one of the six holding tanks or into a flume to the hatchery ponds reserved for brood stock. The adult holding tanks have an up-well water supply, constant overhead water spray and fencing around the tanks. Each adult holding tank (Figure 93) has a 1,500 gallon capacity and is operated

Figure 89: Cowlitz Salmon Hatchery finger weir and holding pool (CA Dept. of Water Resources)

Figures 90 and 91: Cowlitz Salmon Hatchery - Fish shock box - Non-shocked fish on left, shocked fish on right – false weir on right side of photos (CA Dept. of Water Resources)

with the same loading density criteria as the fish trucks, as each tank is emptied directly into a single fish truck. The maximum time adult fish will be held in the holding tanks is 72 hours. All of the separator and adult holding tanks are under a metal roof structure.

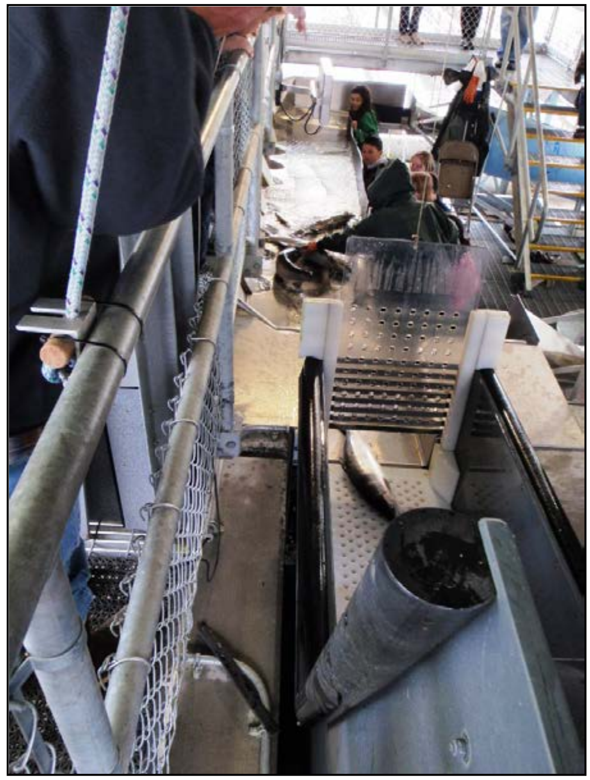

Figure 92: Cowlitz Salmon Hatchery – Fish being moved from shock box to upper sorting table (CA Dept. of Water Resources)

Just like the holding tanks, the fish trucks have a 1,500 gallon capacity. The trucks drive under the elevated holding tanks and are filled by draining the holding tanks through moveable bellows (Figure 94). The trucks are then driven to designated release sites.

At the Cowlitz Trout Hatchery, a physical barrier on Blue Creek, just off the Cowlitz River, guides upstream migrants into a fish ladder which brings fish up into the hatchery and terminates in a central holding pond. The adults are sorted by hand and moved to one of two auxiliary ponds on each side of the central pond. Each auxiliary pond is further subdivided to hold and segregate adult fish. Trucks are loaded by boom or fish are dip netted directly into the trucks. The trucks are then driven to designated release sites.

Tacoma Power operates three 1,500 gallon fish hauling trucks, and the Washington Department of Fish and Wildlife operates one 1,500 gallon fish hauling truck for the Project. The tanks on the trucks have baffles, water circulation capability, and air stones for oxygen delivery. Maximum fish capacity is 130 adult coho salmon, 120 adult steelhead, or 75 adult Chinook salmon.

Figure 93: Cowlitz Salmon Hatchery – Adult holding tank (CA Dept. of Water Resources)

The Tacoma Power trucks have a discharge gate on the back of the tank that is hydraulically controlled for a quick opening into a metal flume that can be extended up to 8 feet behind the discharge gate. All welds on the inside of the tank are rounded off, concave, or convex for best construction, and smoothly finished to prevent damage to fish. All sharp edges are rounded and ground smooth.

Total numbers of adults (Chinook salmon, coho salmon, steelhead trout, and cutthroat trout) transported upstream in the last eight years range from 18,000 to 112,000 annually (Tacoma Power 2004c, 2006d, 2008b, 2009, 2010a). Of these, 90% are of hatchery origin.

Figure 94: Cowlitz Salmon Hatchery Truck Loading (Photo Courtesy of Tacoma Power)

Downstream Passage

As mentioned in the fish passage history section, juveniles migrating downstream from upstream of the all the dams are collected at Cowlitz Falls Dam and transported by truck to the Cowlitz Salmon Hatchery.

After downstream migrants are trucked to the Cowlitz Salmon Hatchery, they are held in specially constructed 8 foot by 50 foot stress relief ponds. Each is capable of holding a single truck load of fish. Fish are allowed to volitionally migrate from these ponds enter the Cowlitz River through a pipeline outfall located just downstream of the Barrier Dam fish ladder entrance.

Bonneville Power Administration, Tacoma Power, and Lewis County Public Utility District are working to improve the collection facilities at Cowlitz Falls. Tacoma Power is currently identifying methods and evaluating technologies to collect downstream migrants. In 2010 they installed a floating surface collector near the north bank of the river just upstream of the dam (LaRiviere 2010). The collector had a wider, shallower entrance than the one at Upper Baker Dam (Wicke 2010) and was connected to a 24 inch diameter pipe to transfer fish downstream to the fish facility. Tacoma Power also installed a Behavioral Guidance Structure (BGS) similar in concept to that used at Bonneville Powerhouse No. 2. The BGS was a 700 foot long, 20 foot deep floating forebay guidance wall, used to guide smolts to the downstream collector (Lewis County Public Utility District 2010).

Tacoma Power is investigating using a three pronged approach for juvenile passage at/near Cowlitz Falls Dam: use the existing Cowlitz Falls Fish Facility, construct a fixed collector using pumped attraction flows upstream of Cowlitz Falls Dam, and construct a Floating Surface Collector in the upper end of Riffe Lake (LaRiviere 2012). Meanwhile, until a more efficient collection facility is constructed, Tacoma Power has a full time crew beach seining to collect smolts that have avoided the Cowlitz Falls facility and entered Riffe Lake (Wicke 2010).

To gain some knowledge into juvenile salmonid behavior in Riffe Lake, the USGS has used acoustic telemetry to follow the movement of 178 steelhead, 179 coho, and 177 Chinook in the reservoir. Monitoring equipment was installed at the midpoint of the reservoir, and in the forebay and tailrace of Mossyrock Dam. The fish were released at the tailrace of Cowlitz Falls Dam. Most of the fish made it to the midpoint of the reservoir, as 92% of the steelhead, 72% of the coho, and 72% of the Chinook

Figure 95: One of two Mayfield Dam Downstream Migrant Collection Louver Arrays (Photo Courtesy of Tacoma Power)

were detected. Steelhead made the quickest journey, with the median time being 2.9 days, compared to 4.1 days for coho and 14.2 days for Chinook. Most of the steelhead made it to the forebay of Mossyrock Dam as well, as 84% were detected with a median travel time of 6.2 days from the release location. Only 36% of the coho made it to the forebay, taking 16.3 days to get there. None of the Chinook made it to the forebay. Also, only one fish (steelhead) was detected in the tailrace of the powerhouse (USGS 2010).

Survival of tagged steelhead in the upper, Cowlitz Falls Dam to midpoint, and lower, midpoint to forebay, reservoir reaches was estimated to be 95% (91-98%; 95% confidence interval) and 90% (85-95%), respectively. For tagged coho salmon, estimates were 73% (66-80%) and 52% (43-62%), respectively. For Chinook salmon, the survival estimate for the upper reach was 72% (65-79%). Many of the fish that made it to the forebay of Mossyrock Dam were later detected upstream at the mid-reservoir monitoring site. Most of the steelhead (79%) and coho (64%) made at least one trip upstream to the mid-reservoir site. The maximum number of upstream trips that were observed was seven for juvenile steelhead and four for juvenile coho. Mobile tracking efforts conducted upstream of the mid-reservoir site found three coho and 32 Chinook that never were detected at the mid-reservoir site (USGS 2010).

Downstream migrants in Mayfield Lake, mostly coho salmon mainly produced in the Tilton River system (the only major tributary to Mayfield Lake), are collected via two louver intake facilities (Figure 95). The intake facilities are 33 feet deep and consist of a series of vertical louvers which are set 2.5 inches apart in a V-formation (Figures 96 and 97). Juvenile fish are directed into a bypass system where they encounter a secondary screening system (Figure 98), where they are guided through the dam in a pipe to a sorting/counting facility (Figure 99).

Fish are separated into one of three holding raceways based on size, then released by pipe to a covered sorting and counting building (Figure 100). There fish are enumerated and tagged, and then moved to holding tanks via flumes or pipes. Non-migrant fish are taken back to Mayfield Lake, while downstream migrants are released into the Cowlitz River at the Mayfield powerhouse tailrace via a pipe and flume (Figures 101 and 102). The Mayfield Dam portion of the Project annually passes an estimated 25,000 to 250,000 salmonid smolts (Zapel et al 2002).

Figure 96: Mayfield Downstream Migrant Collection Louver Array (CA Dept. of Water Resources)

Figure 97: Mayfield Downstream Migrant Collection Facility Louvers (CA Dept. of Water Resources)

Figure 98: Mayfield Downstream Migrant Collection Facility Secondary Screens (CA Dept. of Water Resources)

Figure 99: Mayfield Downstream Migrant Sorting and Counting Facility (CA Dept. of Water Resources)

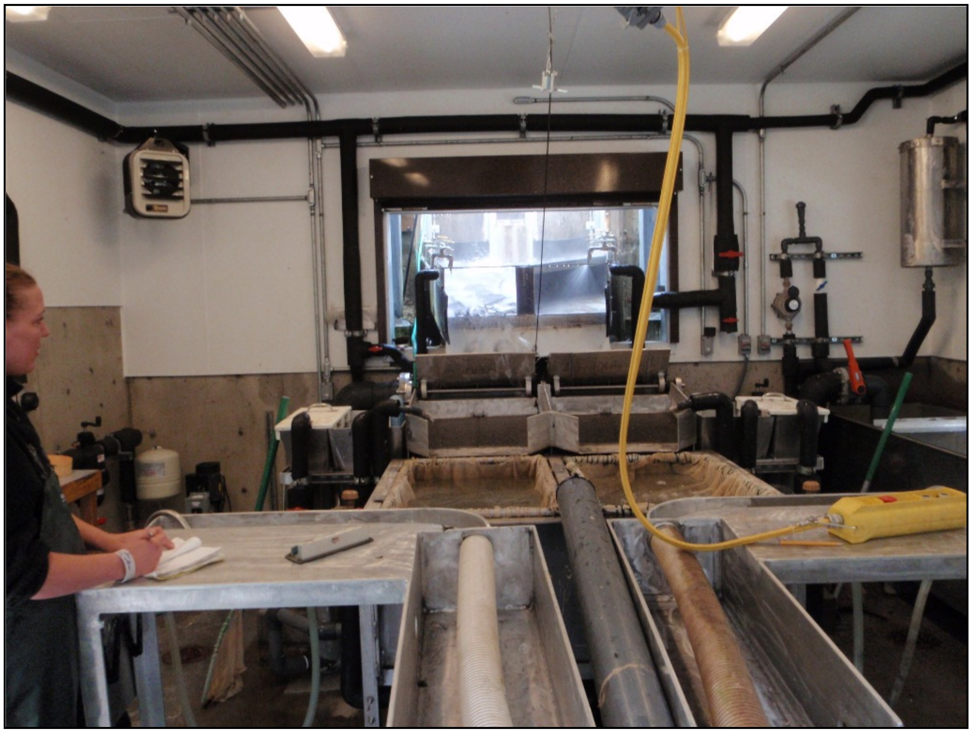

Figure 100: Inside of Mayfield Downstream Migrant Sorting and Counting Building (CA Dept. of Water Resources)

Figure 101: Mayfield Downstream Migrant Bypass Pipe (CA Dept. of Water Resources)

Figure 102: Downstream Migrant Release Flume (Photo Courtesy of Tacoma Power)

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Cushman Project

Text to come.

Lewis River Hydroelectric Projects

Location: The hydroelectric projects consist of three dams on the Lewis River in southwestern Washington (Figure 103). The most downstream dam, Merwin, is about 30 miles north of Portland, OR and 20 river miles from the Lewis River's confluence with the Columbia River.

Owner: PacifiCorp

Dam Name: Merwin	**Hydraulic Height:** 230'	**Year Constructed:** 1931
Dam Name: Yale	**Hydraulic Height:** 309'	**Year Constructed:** 1953
Dam Name: Swift No. 1	**Hydraulic Height:** 400'	**Year Constructed:** 1958

Also associated with these dams is the Swift No. 2 Hydroelectric Project, owned by Public Utility District No. 1 of Cowlitz County (Cowlitz PUD). It is located at the downstream end of the tailrace canal of Swift Dam and therefore there is no dam associated with this project.

Target Species: **S**pring-run Chinook salmon, early- and late-run coho salmon, winter- and summer-run steelhead, chum salmon, Pacific lamprey, bull trout, and sea-run cutthroat trout.

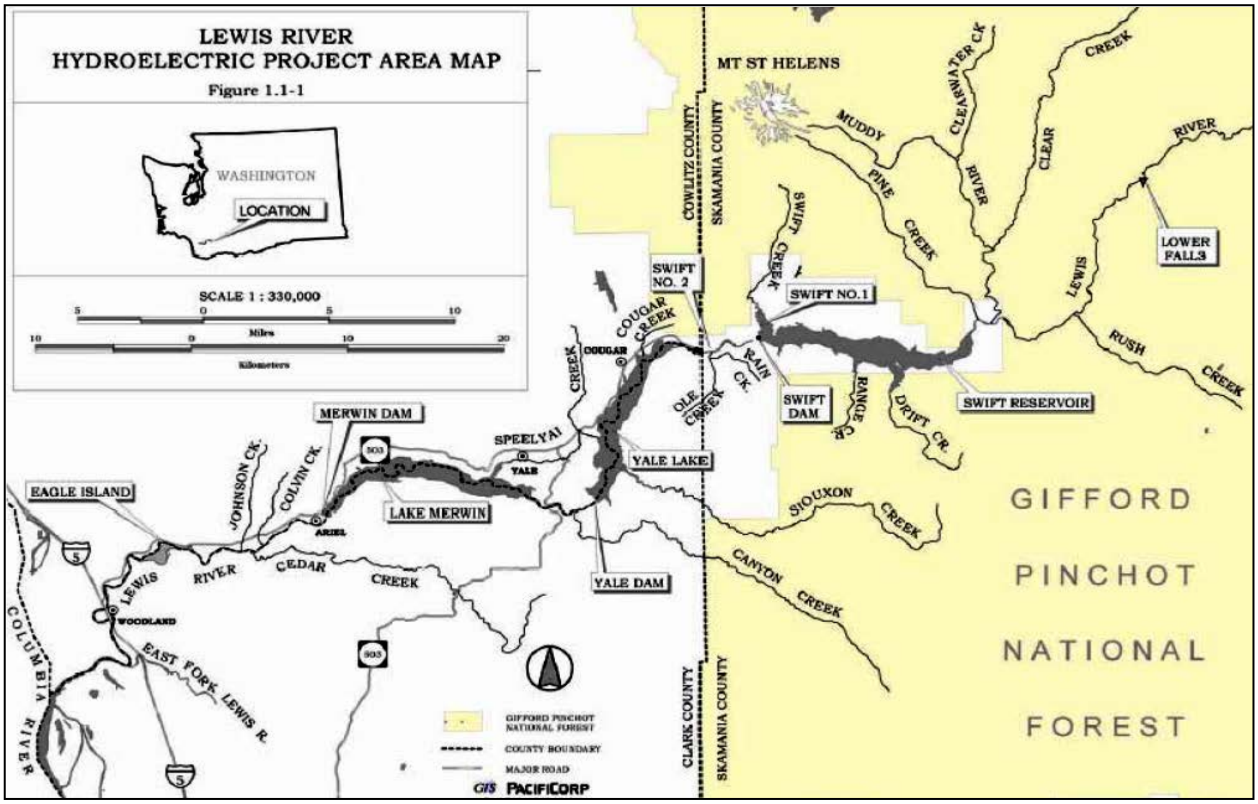

Figure 103: Map of the Lewis River Projects (Courtesy of PacifCorp)

Upstream Passage Summary: Construction of an adult collection facility at the base of Merwin Dam has begun and is scheduled to be completed in January 2014. Once completed, adults will be collected and loaded onto trucks for transport to upstream locations.

Downstream Passage Summary: Construction and deployment of a floating surface collector (FSC) in the reservoir just upstream from Swift Dam was completed in late 2012.

Project Description

The Lewis River, located in southwest Washington, originates in the Cascade Range of the Gifford Pinchot National Forest and flows westward for about 93 miles, joining the Columbia River near Woodland, Washington. It has a drainage area of 1,050 square miles, and two volcanic peaks, Mount St. Helens and Mount Adams, lie on the northern and eastern extremities of the basin (FERC 2008). It is sometimes called the North Fork Lewis River.

The hydroelectric projects on the Lewis River consist of three dams and four powerhouses. The three dams, Merwin, Yale, and Swift, and associated powerhouses are owned by PacifiCorp. In addition, a 70 MW hydroelectric project, Swift No. 2, is owned by Cowlitz PUD and located at the downstream end of the tailrace canal below Swift Dam (Figure 104).

The furthest downstream dam is Merwin Dam (Figure 105), which was completed in 1931. It is a 313-foot-high (230 foot hydraulic height) concrete arch structure that creates 423,000-acre-foot, 14.5-mile-long Lake Merwin. The Merwin powerhouse has a total generating capacity of 136 MW and maximum flow capacity of 11,470 cfs (FERC 2008).

Figure 104: Swift No. 2 Powerhouse (Courtesy of Cowlitz PUD)

Figure 105: Merwin Dam (Courtesy of PacifiCorp)

The middle dam is Yale Dam (Figure 106), a 323-foot-high (309 foot hydraulic height) mainly earthfill embankment dam, which was completed in 1953. It impounds 401,000-acre-foot, 10.5-mile-long Yale Lake, and its powerhouse has a total generating capacity of 134 MW and maximum flow capacity of 9,640 cfs (FERC 2008).

Figure 106: Yale Dam (Courtesy of Low Impact Hydropower Institute)

Figure 107: Swift Dam (Courtesy of the USGS)

The upper dam in the series is 512-foot-high (400 foot hydraulic height) Swift Dam (Figure 107), which retains 755,000-acre-foot, 11.5-mile-long Swift Reservoir. The Swift No. 1 powerhouse has a generating capacity of 240 MW and a maximum flow capacity of 9,120 cfs (FERC 2008). When built in 1958, Swift Dam was one of the highest earthfill dams in the world (PacifiCorp 2013).

Fish Passage History

As Merwin Dam was being constructed, efforts to sustain anadromous fish in the Lewis River through a collection and transport system began and continued until 1957. At that time, possibly due to inadequate juvenile passage downstream, only fall-run Chinook and coho salmon sustained enough of a return to warrant transport upstream, so the passage operation was terminated. Kokanee were introduced in Lake Merwin and Yale Lake in 1957, and in Swift Reservoir in 1961. Only Cougar Creek, a Yale Lake tributary, supports a significant self-sustaining population of kokanee (Thomas 2004).

The following is from NMFS' Modified Fishway Prescriptions for the Merwin Project (2006):

> The Lewis River contains fish from the following ESA-listed Evolutionarily Significant Units (ESU): Lower Columbia River Chinook salmon (fall and spring), Columbia River chum salmon, and Lower Columbia River coho salmon. The Lewis River also contains ESA-listed fish from the Lower Columbia River steelhead distinct population segment. Anadromous fish were blocked at river mile (RM) 21 by the construction of Merwin commencing in 1929 (PacifiCorp and Cowlitz PUD 2000).
>
> Historically, the Lewis River has produced significant numbers of salmonids for harvest by both sport and commercial fisheries. The addition of the Projects to the Lewis River has dramatically reduced fish access to habitat and has resulted in habitat impacts to the mainstem Lewis River below Merwin Dam.
>
> The construction of Merwin dam blocked a majority of the spawning reaches for spring Chinook salmon (WDF 1990) as well as steelhead and coho salmon (PacifiCorp and Cowlitz PUD 2003). The barrier to effective fish passage created by the Projects prevents natural production of these fish in the majority of the Lewis River Basin. The upper river basin contains most of the lower order tributaries that are important spawning and rearing habitat for these species.
>
> Prior to the construction of Merwin, fall Chinook and chum salmon were thought to have spawned in the mainstem reach that is now under Merwin Reservoir (Mclsaac 1990 in PacifiCorp and Cowlitz PUD 2003; Smoker et.al. 1952). WDF (1990) states that, "in 1949, Bryant described the Lewis River as one of the most important producers of coho in the Columbia Basin." Prior to the construction of the dams, fall Chinook salmon were distributed to above Merwin Dam and below the Project, so natural habitat for this population has been reduced by nearly half. Chum salmon spawned in the lower Lewis River downstream from Merwin Dam. Modified flows as well as other influences of the dams have also affected all of these species' populations and their habitats below Merwin Dam. White sturgeon and smelt are two other important anadromous fish of the Lower Lewis River Basin. Sturgeon occur up to the base of Merwin Dam and probably used more of the Lewis River before construction of the dams. There are reports of sturgeon being found in Lake Merwin; apparently isolated there since construction of the project. Smelt spawn in the lower Lewis River.

> Three fish hatcheries have been used in an attempt to mitigate for lost production above Merwin Dam due to the Lewis River Projects. These hatcheries have concentrated the entire watershed's anadromous fish production potential in the reduced quality and quantity of mainstem Lewis River habitat below the project, the remaining wild fish are forced to compete with hatchery production and are often harvested at high hatchery harvest rates, leading to a decline of wild fish.
>
> Fish populations have declined in the Lewis River and a primary factor in that decline is the blockage of passage. Fall Chinook salmon have not declined as much as the other populations and some years have had large numbers. This may be primarily due to unique ocean migration routes (Mclsaac 1990). However, current natural spring Chinook salmon spawning returns to the North Lewis River range from 200 to 1,000 and are almost entirely progeny of hatchery produced fish. Spring Chinook salmon historical adult numbers are estimated to be from 10,000 to 50,000 fish. The fall Chinook salmon current range is from 3,200 to 18,000, and the historical numbers are estimated to be from 18.000 to 20,000. The coho salmon current range is unknown, but it is assumed to be low, and the historical range is estimated to be from 7,500 to 85,000. Chum salmon current natural spawning numbers in the whole Lewis Basin (not just the North Lewis) are estimated to be less than 100 fish, and historical numbers are estimated to be from 120,000 to 300,000. Summer and winter steelhead in the mainstem North Fork Lewis River are not currently monitored by the State of Washington. Summer steelhead North Lewis natural spawning numbers are presumed to be very low, and historical numbers are estimated to be up to 20,000. Winter steelhead current levels in the North Lewis are unknown, but they are presumed to be very low, and historical numbers are estimated to be from 6,000 to 24,000 (LCFRB 2004).

PacifiCorp filed a license application for the Yale Project with the Federal Energy Regulatory Commission (FERC) on May 5, 1999. On April 28, 2004, PacifiCorp filed license applications for the Swift No. 1 and Merwin projects, and Cowlitz PUD filed a license application for the Swift No. 2 Project. The applicants were seeking new licenses to continue to own, operate, and maintain the projects. To resolve all of the issues related to the relicensing of the projects, the applicants filed a comprehensive Settlement Agreement on December 3, 2004. PacifiCorp, Cowlitz PUD, Native American tribes, federal and state resource agencies, three counties, and environmental groups signed this agreement (PacifiCorp et al 2004). Actions within the Settlement Agreement would re-open over 170 miles of historical salmon habitat, improve local flood management, boost recreational opportunities, and preserve the energy resources of the Lewis River (PacifiCorp and Cowlitz PUD 2008). On June 26, 2008, PacifiCorp and Cowlitz PUD were issued new 50-year licenses for the four projects (FERC 2008).

The main goal of the Settlement Agreement was to achieve genetically viable, self-sustaining, naturally reproducing and harvestable populations of the following species: Spring-run Chinook salmon, early and late coho salmon, winter and summer steelhead, chum salmon, Pacific lamprey, and sea-run cutthroat trout. This will be accomplished by collecting and transporting anadromous fish around the three dams to allow access to large amounts of productive fish habitat (PacifiCorp et al 2004). The reintroduction plan will provide access to approximately 117 miles of salmon habitat above Swift Reservoir and contribute to the recovery of listed salmon and steelhead in the lower Columbia River. A report by S.P. Cramer & Associates estimates that the habitat upstream of Swift Dam would produce about 1,400 winter steelhead, 6,200 coho salmon, and 1,200 spring-run Chinook salmon adults under current conditions. Under ideal conditions, they estimate that those numbers might increase to 2,300 spring-run Chinook salmon, 1,800 winter steelhead, and 10,400 coho salmon (Thomas 2004).

To begin the reintroduction process, PacifiCorp began a program, named the Habitat Preparation Plan (HPP), in October 2005 to annually release 2,000 salmon into the watershed above Swift Dam. The goal was to distribute nutrients and stir up gravel in preparation for the formal reintroduction program. These fish may have spawned and produced fry but PacifiCorp was not responsible to collect the downstream migrants. Once the formal reintroduction of adults begins at Swift Reservoir (one year before the Swift Downstream collector is to be completed), the Swift HPP program will cease. An HPP program at Yale Reservoir will begin in year 2016 unless NMFS and the U.S. Fish and Wildlife Service decide against reintroduction of salmon and steelhead into Yale and Merwin reservoirs (Shrier 2009).

Formal reintroduction of salmonids into the upper Lewis River will be a phased approach. Phase one begins one year prior to the completion of the upstream collection facility. Initially, PacifiCorp will transport adults to above Swift Dam. For collection of upstream migrants, the Settlement Agreement states that PacifiCorp shall construct and operate an adult collection and transport facility (Shrier 2009). Adult spring-run Chinook salmon, coho salmon, and steelhead will be trapped below Merwin Dam and transported by trucks upstream to above Swift Reservoir. Hatchery fish will be initially used to start the reintroduction program and over time, and as naturally produced fish increase in numbers, hatchery supplementation would taper off (Thomas 2004).

The upstream passage facility was required to be completed and operational by December 26, 2012 (Shrier 2009). Construction of the facility began in April 2011, but in the fall of 2011 encountered site conditions that resulted in the redesign of some of the structural components. The new expected completion date for the facility is January 23, 2014 (PacifiCorp 2012). The Settlement Agreement also called for a floating surface collector in Swift Reservoir to capture downstream migrants (Shrier 2009). Construction of this facility was completed in late 2012 (see Current Fish Passage for details).

In future phases, similar upstream and downstream collection facilities will be installed to open up approximately 57 miles of habitat above Yale Lake and Lake Merwin in years 13 and 17 respectively. However, information gathered from the reintroduction effort into Swift Reservoir may indicate these actions are no longer appropriate. If reintroduction does not occur at Lake Merwin and Yale Lake, a $30 million “in-lieu fund” will be used for other projects supporting fish habitat restoration and enhancement in tributaries upstream and downstream from the projects (PacifiCorp et al 2004).

The upstream collection facility below Merwin Dam was estimated to cost $50 million and the downstream collector at Swift Dam $60.3 million (Paulu 2012). Funding will also be provided for habitat restoration actions to improve habitat function and productivity. Over the proposed 50-year license term, PacifiCorp will provide approximately $290 million and Cowlitz County PUD $19 million for protection, mitigation and enhancement measures covering fish, wildlife, recreation, cultural resources and flood management (FERC 2004).

Current Fish Passage

Upstream Passage

PacifiCorp is currently constructing Merwin Upstream Collection and Transport Facility at the base of Merwin Dam. When it is completed, upstream migrants will be attracted to the facility by river water exiting a fishway. The fish will swim up the short fishway and into a trap basket. The basket will be hoisted and the fish delivered to a holding tank near the sorting area. Sorting of fish will be based on species, origin (wild or hatchery), and point of origin (determined by tags or clips). Fish will then be loaded onto trucks for a trip to the hatchery or upstream of the dams to be released in the upper Lewis River and its tributaries (PacifiCorp 2013).

Downstream Passage

A floating surface collector (FSC) was completed and deployed in Swift Reservoir in 2012. Juvenile fish, the offspring of the salmon and steelhead that spawned upstream of Swift Reservoir, come downstream through the reservoir as they migrate to the ocean. The Swift Reservoir Fish Facility is a 170’ by 60’ FSC (Figures 108 and 109) which creates flow conditions to attract these fish by the use of large pumps. Full-depth, shore-to-shore nets guide the juveniles, which are typically 3 - 6 inches long

Figure 108: Swift FSC Fish Entrance (Courtesy of PacifiCorp)

at this stage in life, into the net transition structure. This structure provides an attachment point for the net and helps transition fish from the reservoir into the FSC. Once in the FSC, the fish pass the primary fish screens, where most of the water exits the channel. The fish then enter a narrower secondary fish screen channel, where much of the remaining flow is removed. All screens in the primary and secondary channels meet the NMFS approach velocity criterion of 0.4 fps (Shallenberger et al 2009).

At the end of the secondary channel, fish and the remaining water pass over a ramp weir, dewatering screen, and fry separator (Figure 110). The fry separator consists of narrowly spaced, parallel bars oriented along the bottom of the channel which will allow fry and the remaining water to pass between them and into a small flume. The fry then move down the small flume to one of the two fry holding tanks. Ten percent of the fry are biologically inspected and hand counted (Shallenberger et al 2009).

The larger fish slide along the fry separator bars and immediately onto a smolt separator. The smolt separator is basically the same design as the fry separator, except that the bars are farther apart, allowing fish smaller than about 11 inches to pass through them. These fish drop into the smolt flume,

Figure 109: Swift FSC (Courtesy of PacifiCorp)

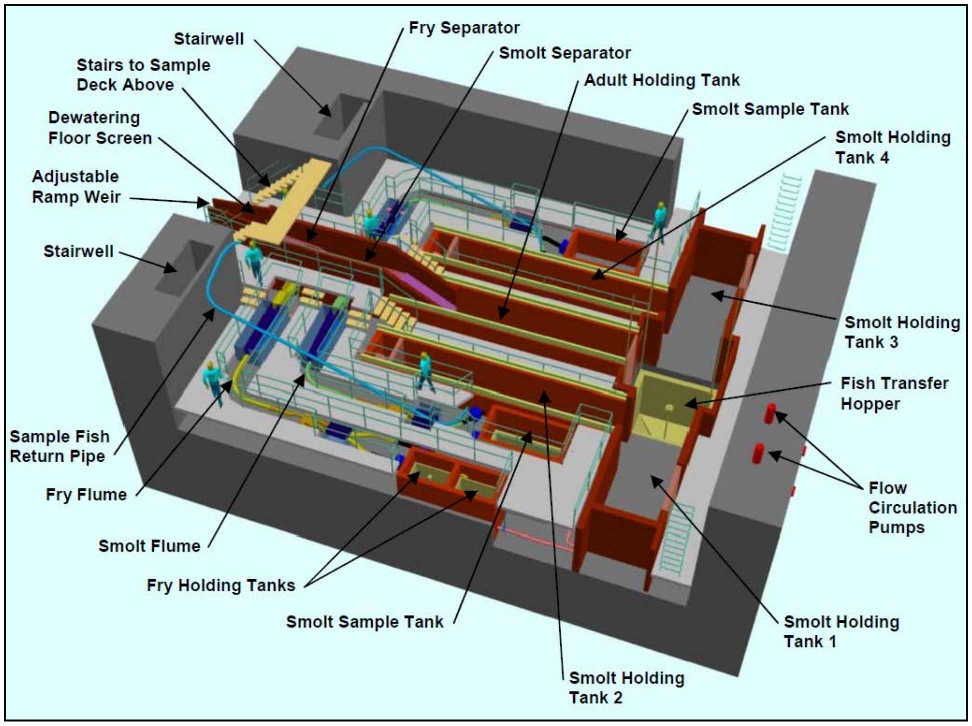

Figure 110: Swift FSC Holding and Sorting Area (Shallenberger et al 2009)

which takes them to one of four holding tanks. Each tank is sized to hold the number of fish that can be safely loaded into a 1,800-gallon truck. As with the fry, ten percent of the smolts are biologically inspected and hand counted (Shallenberger et al 2009).

Fish that do not pass through the bars of the smolt separator end up in the adult holding tank. It is thought that he majority of fish in the adult tank are actively migrating downstream, such as steelhead kelts, and these fish are transported downstream of Merwin Dam (Shallenberger et al 2009).

Fish to be transported are crowded from the holding tanks into a 1,800-gallon hopper. The hopper is then lifted and emptied into a transport truck (Shallenberger et al 2009). Fish are transported to a release pond downstream of Merwin Dam. The release pond provides the fish a place to recover from the collection and transport process, and allows for the study of post-transport survival. Fish are able to volitionally leave the release pond (Shrier 2009).

The FSC is located near the south end of Swift Dam, anchored by a mooring tower and connected to the dam by a 650-foot-long access trestle (Figure 111). The tower and trestle are supported on piles, and the FSC rises and falls with the reservoir level (PacifiCorp 2013).

Several sites were considered for the FSC at the beginning of the project. These sites were assessed based on biological and operational criteria, and the physical constraints of the dam and intake. As part of the assessment, PacifiCorp conducted fish tracking studies in the reservoir and a computational fluid dynamics (CFD) model of the reservoir near the dam (Shallenberger et al 2009).

Figure 111: Swift FSC and Access Trestle (Courtesy of PacifCorp)

The fish tracking studies used radio or 3-D acoustic tags on Chinook and coho salmon smolts to determine if they can negotiate the 11.5-mile-long reservoir and the best location for collecting them. For the radio tag studies, 60 Chinook and 60 coho smolts were released about 200 meters upstream from Swift Reservoir (Figure 112). The studies showed that both Chinook and coho smolts had no problem

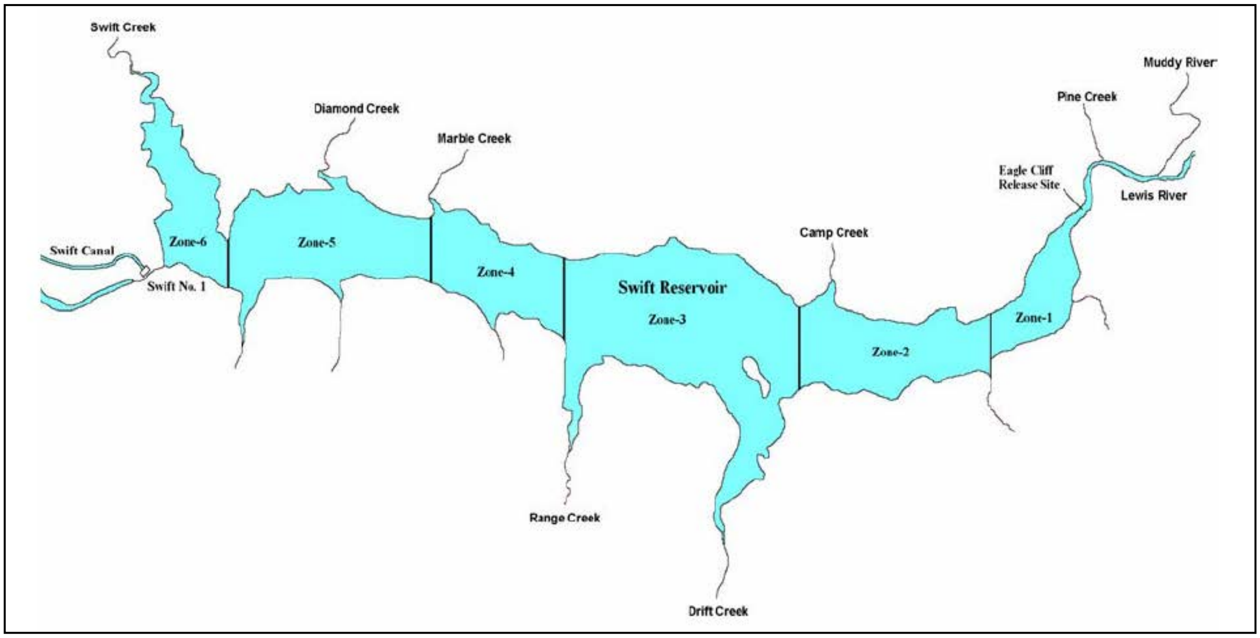

Figure 112: Swift Reservoir – Dam is on left and fish release site on right (PacifiCorp and Cowlitz PUD 2004)

moving through the reservoir to the intake structure. In general, the Chinook smolts migrated through the reservoir slower than the coho smolts. Chinook migrated at a median rate of 3.4 km/day compared to 5.2km/day for coho. Therefore, the median travel time to the dam was greater for Chinook (5.5 days) than coho (3.6 days). Although Chinook exhibited a longer migration period, survival to the dam was nearly as high for Chinook (85.0%) as coho (90.0%) (PacifiCorp and Cowlitz County PUD 2004). Neither Chinook nor coho sounded and exited the forebay through the turbines (Shallenberger et al 2009).

For the 3-D acoustic tag study, 50 Chinook and 50 coho smolts were released in the reservoir just upstream of the intake forebay. This study also showed that both Chinook and coho smolts had no problem finding their way to the dam. Both the radio tracking and 3-D acoustic studies showed:

- Chinook and coho moved rather quickly through the reservoir and arrived in the dam in high numbers.
- Downstream migrants did not favor one side of the reservoir over the other.
- Downstream migrants stayed in the upper 50 feet of the reservoir (Shallenberger et al 2009).

To further assess potential locations for a FSC, a CFD model of the reservoir from the dam to approximately one mile upstream was developed. The CFD model evaluated the existing flow patterns in the reservoir, FSC attraction flow, and the impacts of discharges from the FSC. All CFD simulations were run for steady and uniform flow conditions. Since the Swift No. 1 powerhouse is used as a peaking plant, steady flow conditions typically do not occur. However, unsteady flow modeling was considered to be an unfeasible approach due to the limitations of CFD models and the complexity involved. Instead, by running simulations with the powerhouse operating at its maximum capacity and with the powerhouse off, it is expected that the flow patterns resulting from unsteady operating conditions will reside between the two extremes (Shallenberger et al 2009).

Figure 113: Swift Intake Channel at Low Reservoir Elevation (Courtesy of PacifiCorp)

The CFD results were reviewed with the assumption that juveniles would likely follow the flow lines in the reservoir, although it was recognized that this may or may not be true, as this assumption cannot fully consider juvenile behavior. Instead of following flow lines, juveniles may follow shorelines, shear zones, log booms, or other physical or hydraulic features or stimuli (Shallenberger et al 2009).

After considering the fish tracking studies and the CFD modeling, the conclusion was that the FSC should be located as close to the intake as possible. However, due to the restricted width of the intake channel, the FSC could not be located within the channel (Figure 113). As a result, the FSC will be located just upstream of the intake channel (Shallenberger et al 2009).

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Yakima River Dams

Text to come.

Bonneville Hydroelectric Project

Location: Columbia River, Oregon and Washington, approximately 40 miles east of Portland, OR. The dam is located at river mile 146.1.

Owner: United States Army Corps of Engineers (USACE) Portland District

Dam Name: Bonneville **Hydraulic Height:** 50' **Year Constructed:** 1937

Target Species: Chinook salmon, coho salmon, sockeye salmon, and steelhead

Upstream Passage: Fish Ladders

Downstream Passage: Juvenile bypass, corner collector, spillway, turbines

Description

Bonneville Dam is located on the Columbia River at River Mile 146.1 (Figure 114). The dam is the furthest downstream dam on the Columbia River. The run-of-river dam spans the Columbia River between Oregon and Washington, roughly 40 miles east of Portland, Oregon. It consists of several structures that along with three islands, span the width of the river. The structures, listed from north to south, are: the second powerhouse, the spillway, the first powerhouse, and the navigation lock. A schematic showing the layout of the dam and its features is shown in Figure 115. Lake Bonneville is the 48 mile long reservoir created by the dam. The main function of the dam is hydroelectric power generation and to back up water for river navigation. The dam is owned and operated by the USACE Portland District and the power is marketed by the Bonneville Power Administration. There are two powerhouses located at the dam. The first powerhouse, on the south side of the river, was constructed during dam construction and the second powerhouse, on the north side of the river, was completed in 1982. The first powerhouse has two 43 MW generating units and eight 54 MW generating units, with a total nameplate capacity of 518 MW. The second powerhouse has eight 66.5 MW generating units, with a total nameplate capacity of 532 MW. The hydraulic capacities of the first and second powerhouses are 136,000 cfs and 152,000 cfs, respectively. The spillway is located in the center of the river and is 1,450 feet long and has 18 gates. There are two navigation locks at Bonneville, although only one is open to river traffic. The first lock, built in 1938, has a 500 foot long by 76 foot wide chamber, with a maximum lift of 70 feet. The first lock was shut down and replaced by the second lock, built in 1993, which has a 675 foot long by 86 foot wide chamber, with a maximum lift of 70 feet.

Figure 114: Map of Columbia River Basin Dams (source: USACE)

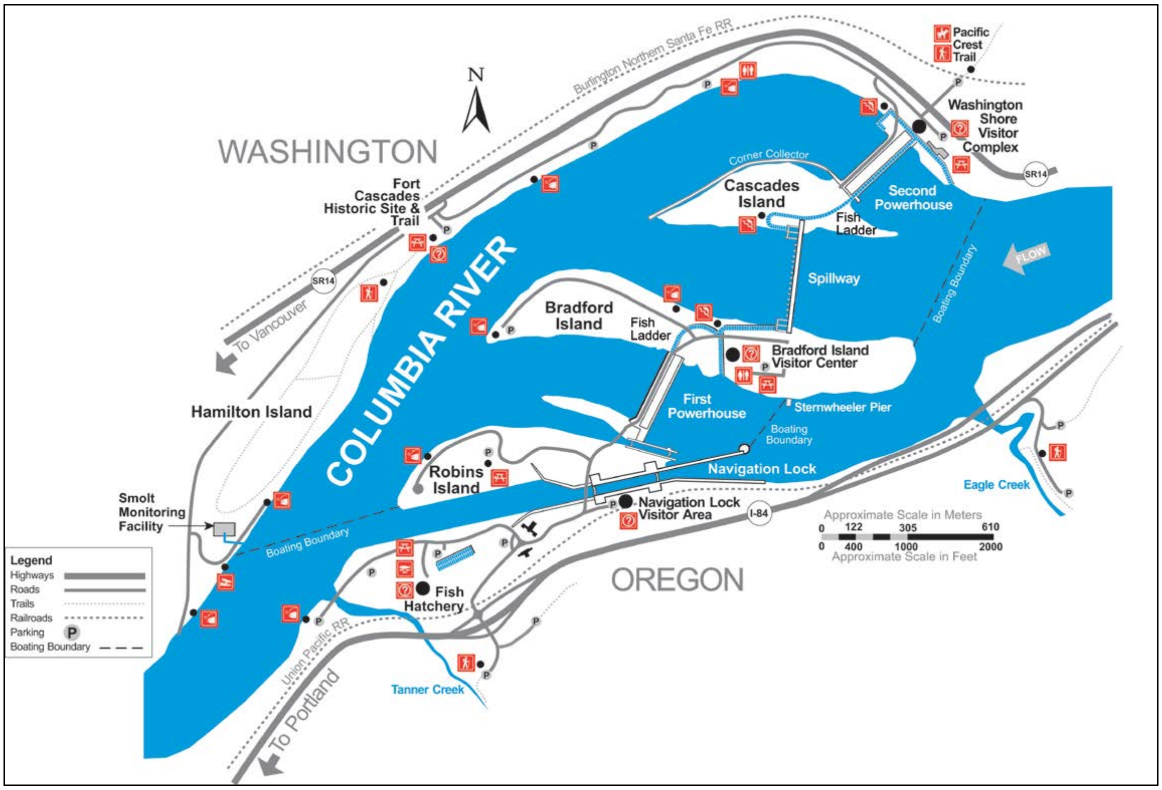

Figure 115: Schematic of Bonneville Dam and associated facilities (source: USACE)

Fish Passage History

A fish passage system was built when Bonneville Dam was initially constructed. The total design and construction cost of the system was almost $7 million, roughly 15 percent of the original project costs. The system consisted of three fish ladders, two pairs of fish lifts, and four special bypasses to help fish pass the dam.

Fish counts of adult fish moving upstream through the ladders have occurred since 1938. There are between 700,000 and 1.5 million adult salmon and steelhead migrating upstream in a typical year. Between 24 and 43 million salmon and steelhead fingerlings migrate downstream past Bonneville Dam in a typical year. Besides salmon and steelhead, other species present at Bonneville Dam are shad, sturgeon and lamprey. (USACE [date unknown])

There is a fish hatchery at Bonneville Dam which was built by the USACE and is now operated by the Oregon Department of Fish and Wildlife.

Upstream Passage

Currently, there are three primary fish ladders at Bonneville Dam for upstream passage. Figures 116 through 118 show detailed layouts of these facilities. The USACE's 2010 Fish Passage Plan has a good description of the components used for upstream passage:

> The Powerhouse One [first powerhouse] collection channel and A-branch ladder join the south spillway entrance and B-branch ladder at the junction pool at the Bradford Island ladder to form the Bradford Island fishway. The downstream migration channel (DSM) is

also used for adult passage from early September, as soon as fish screens are installed, through, at least, December 15. The system consists of 12” orifices, six STSs [submersible traveling screens] and VBSs [vertical bar screens], and a migration channel that runs south and out the ice and trash sluiceway.

The Cascades Island ladder at the north side of the spillway is connected to the Washington shore ladder by the upstream migrant transportation (UMT) channel. The Powerhouse Two [second powerhouse] collection channel and north and south monoliths join the UMT to form the Washington shore fishway.

Bradford Island, Cascades Island and the Washington shore fishways have counting stations. The Washington Shore ladder has an adult fish sampling facility. All four collection systems have auxiliary water supplies for fish attraction. (USACE 2010)

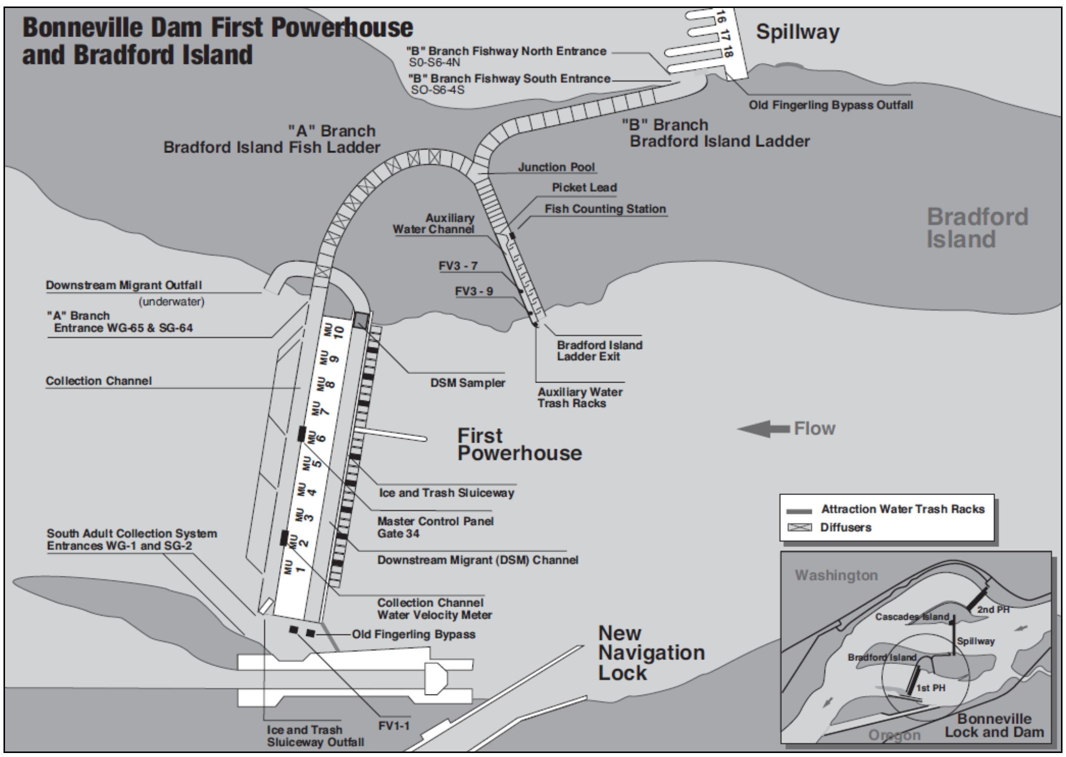

Figure 116: Bonneville Dam First Powerhouse and Bradford Island Fish Ladder (source: USACE)

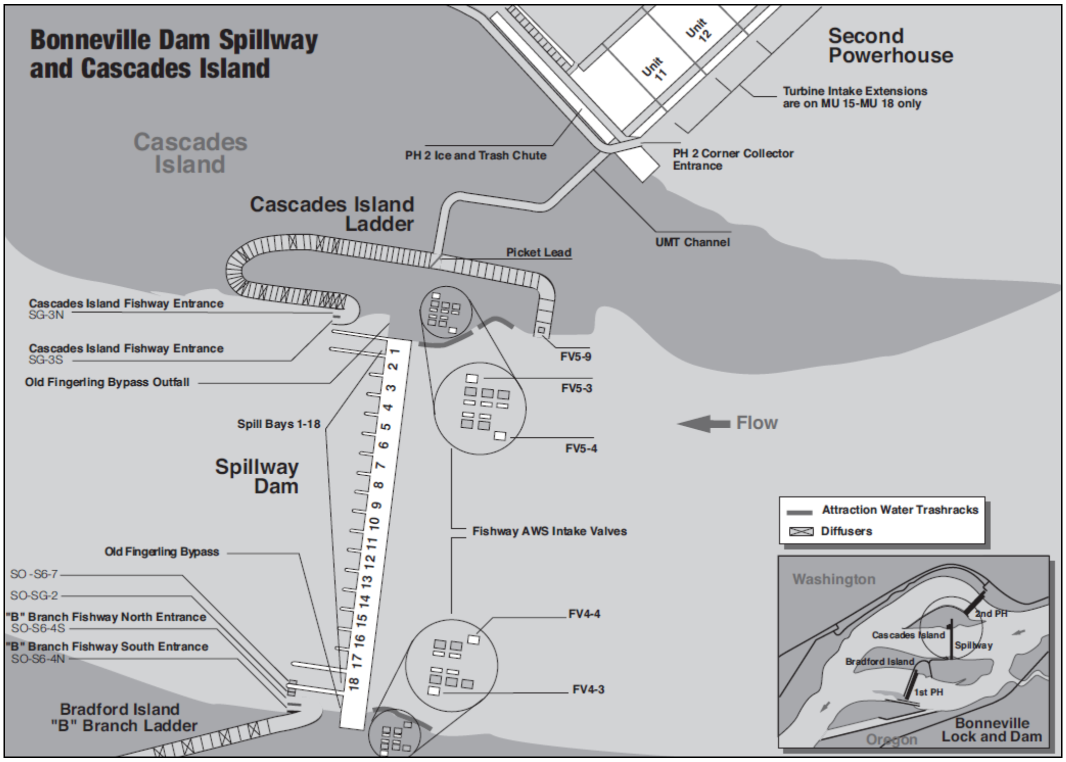

Figure 117: Bonneville Dam spillway, Cascades Island Fish Ladder and Upstream Migrant Transportation Channel (UMT). (source: USACE)

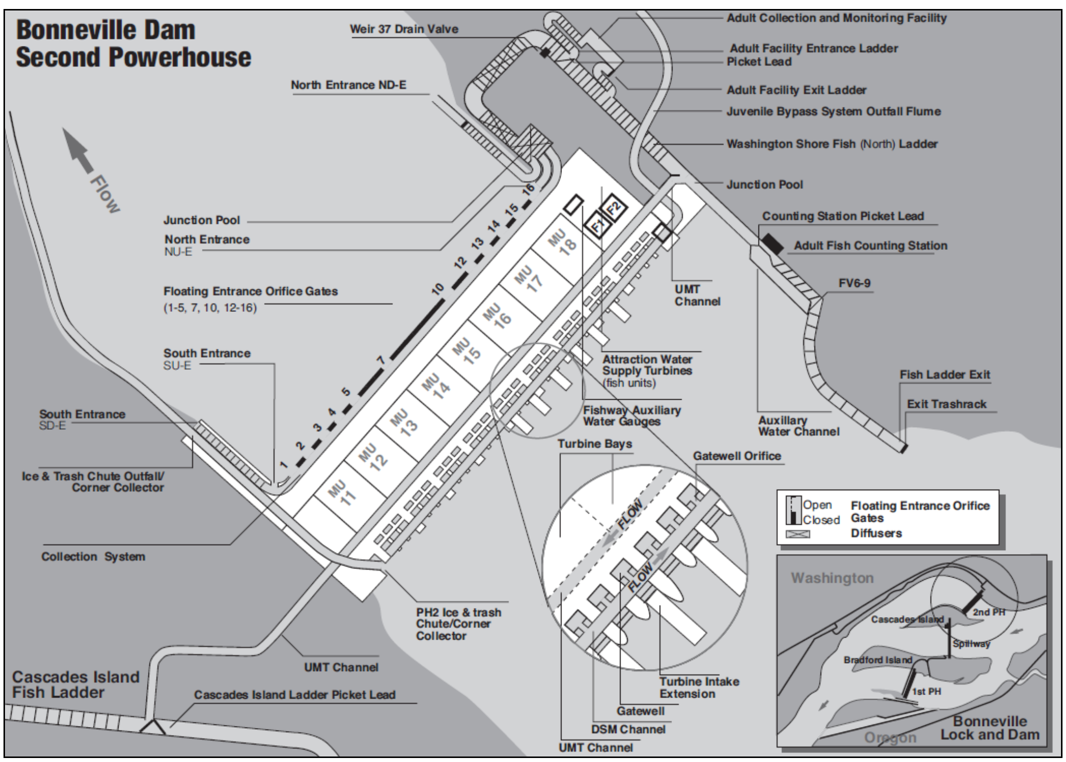

Figure 118: Bonneville Dam Second Powerhouse and Washington (North) Fish Ladder (source: USACE)

Downstream Passage

The current downstream passage methods for the first powerhouse are via an ice and trash sluiceway or through minimum gap runner turbines. The second powerhouse has a juvenile bypass system. Within the powerhouse, the system consists of submersible traveling screens, vertical bar screens, and 12.5” orifices into gatewells which flow into the bypass channel. A 48” transport pipe connects the bypass channel to the dam tailrace. Two transport pipes, a 48” pipe for the high outfall and a 42” pipe for the low outfall, transport fish to the outfall location downstream. The system also has a sampling facility on-site. Fish that are not diverted by the screens at the second powerhouse pass through the turbines. Some fish moving in the center of the river may pass over the spillway. Figure 119 displays the layout of the juvenile fish passage facilities at Bonneville Dam. Figure 120 shows a detailed view of the juvenile fish monitoring facility and outfall flumes.

In 2004, construction of the Bonneville Dam Second Powerhouse Corner Collector was completed. It was built to augment the juvenile bypass system. Roughly 30% of all downstream migrants that pass through Bonneville Dam go through the corner collector (BPA 2006). The Corner Collector was designed to operate over a range of flows, from approximately 3375 to 6570 cfs. The Baseline Cost Estimate, prior to construction, was $55.2 million (USACE 2002). The “Surface Passage Systems and Removable Spillway Weirs, Lower Columbia and Snake River Dams” document describes the collector and its development:

> The corner collector facility includes a 2,800-foot long transportation channel, a 500-foot long outfall channel, a plunge pool, and modification of the ice and trash chute to ensure safe passage. The bypass flume begins at the southeastern corner of the [second] powerhouse, where a gate can be removed to allow approximately 5,000 cubic feet per second of water to spill into the chute carrying fish downstream. The fish will re-enter the river just beyond the westernmost tip of Cascades Island, over one-half mile downstream in faster moving water away from predators. A plunge pool excavated into the river bottom will permit fish to re-enter the river and avoid injuries that might occur at lower river levels.
>
> Field testing in 1998 revealed that about 40 percent of juvenile fish in the forebay (area directly upstream) of the Bonneville Dam Second Powerhouse were passing the dam through the existing ice and trash chute (a chute used to clear floating debris from the reservoir behind the dam) when that facility was operated. By modifying the ice and trash chute into a surface flow bypass system at that location, the Corps estimates the number of juveniles guided into the corner collector will be increased to 50 to 60 percent, passed without injury and returned safely to the river. The corner collector will work in conjunction with the existing Second Powerhouse screened juvenile bypass system, which had survival improvements completed in 1999. Together, these non-turbine routes are estimated to pass about 90 percent of all juvenile fish at the Second Powerhouse with an estimated survival rate of greater than 95 percent. (salmonrecovery.gov 2004)

The USACE Design Documentation Report No. 47 further describes the corner collector:

> The system features will consist of the following: the existing Ice and Trash Chute intake at the upper pool will be modified with a new operating gate, an ogee, and channel

> improvements from the intake to the downstream face of the powerhouse. A new concrete channel will be constructed on the north bank of Cascade Island from the downstream face of the powerhouse to the downstream tip of Cascade Island. The new channel and outfall will be supported on a structure extending approximately 400-feet off the downstream tip of Cascade Island to a point where it cantilevers 10-feet off of the support structure. The system discharges into a plunge pool excavated in the river bottom. (USACE 2002)

In 2008, a prototype Behavioral Guidance System (BGS), 700 feet long and 10 feet deep, was installed in the forebay of the second powerhouse (Figure 121). The purpose of the BGS was to increase the passage of juvenile salmon into the corner collector. Since the corner collector is known to be a relatively benign route for downstream passage, it was expected that passage survival of juvenile salmon and steelhead would increase at the second powerhouse. The USACE Portland District asked Pacific Northwest National Laboratory (PNNL) to conduct an acoustic telemetry study to evaluate the prototype BGS. The PNNL studied approach and passage distribution of juvenile salmon relative to the BGS location. They also estimated route-specific survival of tagged juvenile salmon and steelhead passing downstream through the second powerhouse. The PNNL found the BGS increased passage percentage into the corner collector for yearling Chinook salmon by up to 9%, but no improvements were observed for subyearling Chinook or juvenile steelhead when comparing 2008 study results to passage distributions observed in 2004-2005 radio-telemetry studies. However, it should be noted that in 2004-2005 all turbines were operating, while in 2008 one turbine unit was offline, making it difficult to compare passage percentages. The BGS was designed to be used with total powerhouse operation. Overall, the corner collector efficiency was 75% for juvenile steelhead, 49% for yearling Chinook salmon, and 40% for subyearling Chinook salmon. For the relatively high flow year in 2008, there were high survival rates for all passage routes of the second powerhouse. For yearling Chinook salmon, paired and triple release survival estimates were at or near 100% for the corner collector and juvenile bypass system, and 97% -98% for turbine routes. For subyearling Chinook salmon, paired and triple release survival estimates were near 100% for the corner collector and juvenile bypass system, and 95% - 97% for turbine routes. There were no controlled releases for juvenile steelhead, so survival was evaluated using single-release Cormack-Jolly-Seber models. The PNNL found survival estimates near 98% for steelhead for all routes at the second powerhouse through the tailrace. (PNNL 2010)

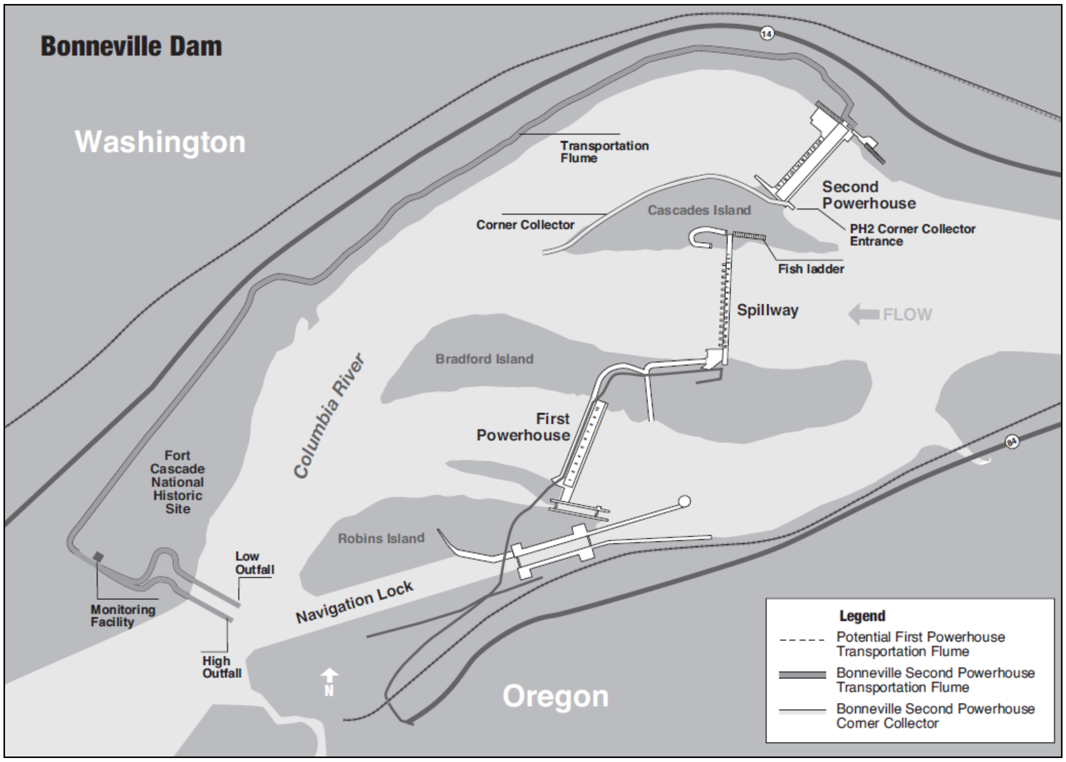

Figure 119: Bonneville Juvenile Fish Passage System (source: USACE)

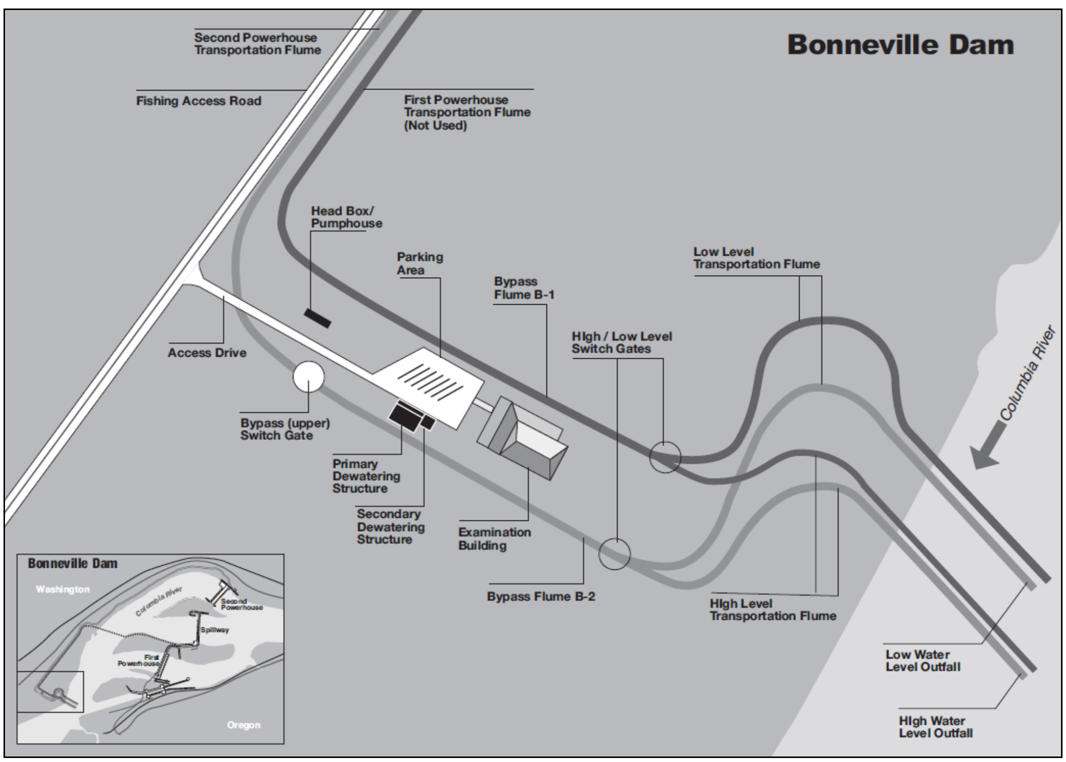

Figure 120: Bonneville Dam Juvenile Fish Monitoring Facility and Outfall Flumes (source: USACE)

Figure 121: Behavioral Guidance System in the second powerhouse forebay (source: USACE)

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Rocky Reach Hydroelectric Project

Location: Columbia River, Washington, 95 miles east of Seattle. The dam is 473 miles upstream of the mouth of the Columbia River.

Owner: Chelan County Public Utility District

Dam Name: Rocky Reach **Hydraulic Height:** 112’ **Year Constructed:**1961

Target Species: Chinook salmon, sockeye salmon, coho salmon, steelhead

Upstream Passage: pool and weir fish ladder

Downstream Passage: Juvenile Bypass system – surface collector and bypass pipe, spillways, fish-friendly turbines

Description

The Rocky Reach Hydroelectric Project (Rocky Reach) is located on the Columbia River in north central Washington State (Figure 122). The dam is 473 miles upstream of the mouth of the Columbia River. It is located downstream of Wells Dam, which is the furthest upstream dam on the Columbia River that provides anadromous fish passage. Initial construction started for the Rocky Reach Hydroelectric Project in 1956 and commercial operation began in 1961. The primary purpose for construction of the dam was power production and flood control. The project has 11 generators, a generator nameplate capacity of 1300 megawatts, and 12 spillway gates. The spillway gates open individually to allow water to pass through separate spillway bays. A major powerhouse upgrade that started in 1995 and was completed in 2006 included installing new adjustable-blade turbine runners on all of the 11 generating units. The upgrade improved efficiency, resulting in more power generation and lower maintenance costs, thereby increasing revenues. The new turbine runners are also more fish friendly.

Figure 122: Map of Columbia River Basin Dams (source: USACE)

Fish Passage History

The pool and weir fish ladder, used for upstream passage, was built during the original construction of the dam in 1959 to 1961. There were no initial downstream passage facilities included in the construction of the dam. For downstream passage, fish passed via the spillways and through the turbines.

Upstream Passage

There are several components of the upstream fish passage facilities at Rocky Reach. Chelan County PUD's 2010 Operations Plan for Rocky Reach provides an overview:

> These facilities consist of a fishway with the right powerhouse entrance (RPE) and left powerhouse entrance (LPE), powerhouse collection and transportation channels, a spillway tunnel channel, a main spillway entrance (MSE), and a fish ladder. The LPE is

> located at mid-dam between the powerhouse and spillway. The RPE is located on the south end of the powerhouse. The fishway includes a counting station on the right bank.
>
> The adult fish passage facilities include three turbine-driven propeller-type pumps that supply water from the tailwater of the Project for the powerhouse fishway entrances, most of the spillway entrance flow, and the six orifice gates along the powerhouse collection channel. Additional gravity-flow water can be supplied at the main spillway entrance to maintain the agreed upon criteria for that entrance. The powerhouse collection, left powerhouse, and spillway channels merge in the junction pool area to form the transportation channel that guides fish to the lower end of the fish ladder. The fish ladder exit is located on the right bank of the Columbia River. (Chelan County PUD 2010a)

The fish ladder at Rocky Reach is a pool and weir type ladder. Each weir has a “perched orifice”, a square hole in the weir wall located on alternating sides of each weir. Fish have the option of passing through the orifice instead of going over the weir (Hemstrom, personal communication, 2010c). The pools are 16 feet wide by 16 feet long. The total elevation gain through the ladder is 90 feet. Each weir is set one foot below the previous weir (Hemstrom, personal communication, 2010d). A photograph of the fish ladder is shown in Figure 123.

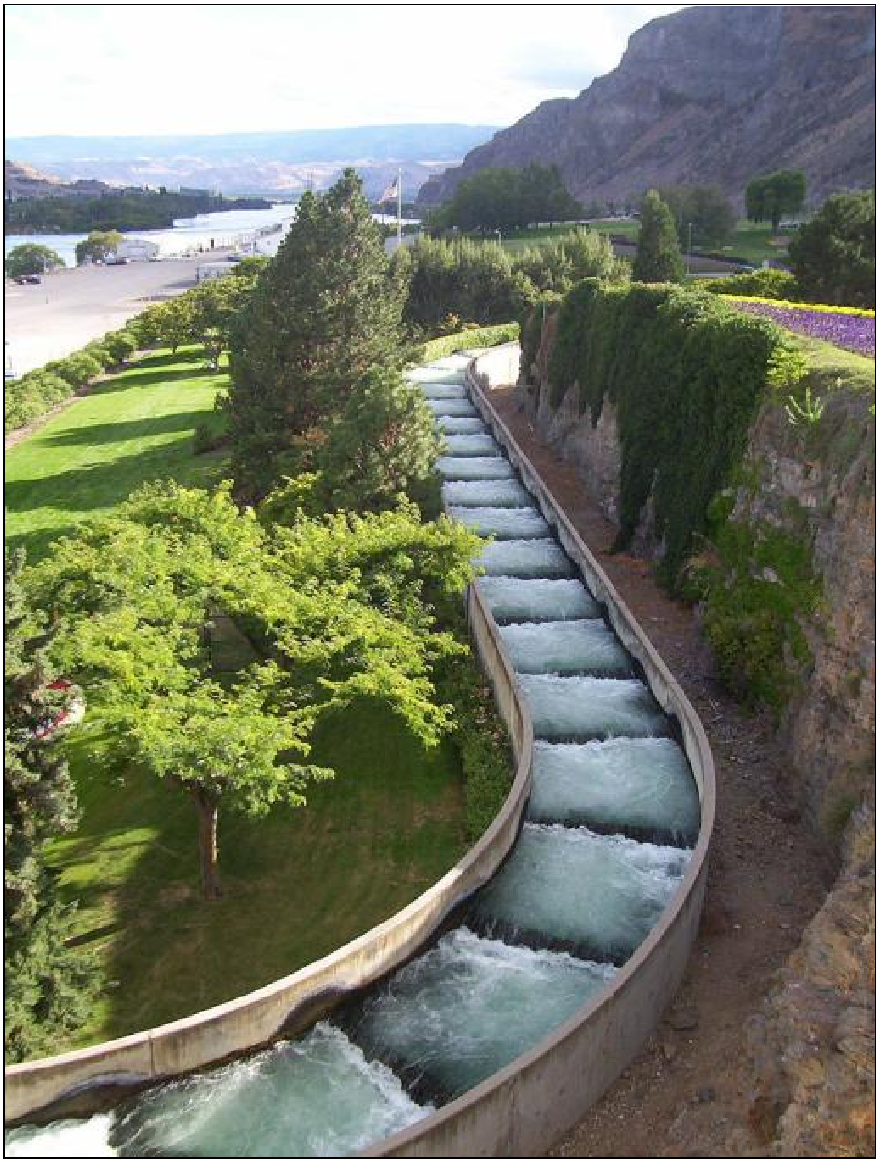

Figure 123: Pool and weir fish ladder at Rocky Reach Dam (This file is licensed under the Creative Commons Attribution ShareAlike 3.0 License. Photo taken by: Garrett Fitzgerald)

Downstream Passage

A prototype collection and bypass system was installed in 1995. This was added after trying prototypes of more traditional screening systems that worked on other Columbia River hydroelectric projects, but not on Rocky Reach. The surface collector was designed to use natural and turbine-induced surface currents in the upper 60 feet of the river to provide fish with an alternative to passing through the turbine intakes. Some benefits of this design include the minimal volume of flow that is lost and low installation cost. The prototype surface collection system was modified each year, based upon test results from the previous year, until the configuration was considered satisfactory. A permanent surface collection system (Figures 124 through 127) was installed in 2002-2003. The final design uses 29 pumps to create a strong current which helps attract juvenile fish to the collector. (Chelan County PUD [date unknown-b])

An email received from Steven Hemstrom (Chelan County PUD) on February 18, 2010, stated that the total design, engineering and construction costs for the system were $107 million. Another email from Hemstrom on August 4, 2010 describes the system in detail:

> Flow from the forebay enters the Surface Collector (SC) at a rate of 6,000 cfs (3,000 cfs per entrance – two entrances). Smolts enter one of two SC channels in the forebay (each 20 ft wide x 57 ft deep x 191 ft long) where flow from each channel is dewatered through fine screening from 3,000 cfs down to 120 cfs (water is pumped back into the forebay). Water velocity in the SC channels is maintained at 2.85 fps. Fish enter the bypass pipe from the SC channels with a flow of 240 cfs. Vertical Barrier Intake Screens in turbine units 1 & 2 also deliver screened fish and 120 cfs flow into the Bypass pipe. Total flow inside the bypass pipe delivering smolts from the forebay and turbine units is 360 cfs, giving fish a transport time of approximately 7-8 minutes. Water and fish are released several hundred yards downstream of the dam in a fast moving area of the river. Prior to exiting to the downstream side of the Project, the pipe runs through a juvenile sampling station where smolts are sampled each day from 0800-1130. Juvenile and adult separation occurs here also. The sampling facility serves to examine the condition of the bypass fish, provide estimates of run-timing for each species past Rocky Reach dam, and to collect run-of-river smolts to conduct Project Survival studies required by Chelan PUD's first and only in the nation, Anadromous Habitat Conservations Plans (HCPs) for the Rocky Reach and Rock Island Projects.
>
> Chelan PUD has, since 2003, estimated survival for juvenile Upper Columbia River (UCR) yearling spring Chinook, UCR Steelhead, and Sockeye via acoustic and PIT tag studies for the Rocky Reach HCP. Smolt survival for fish using the bypass system is averaging 99.9 percent during survival studies. Bypass efficiency (proportion of smolts using the bypass as compared to turbines and spill) is very high, achieving 50-70% for steelhead, 40-50% for sockeye, and 40-47% for Chinook. The Rocky Reach bypass system is also known to pass more juvenile bull trout than any other facility in the mainstem Columbia River. Permanent Spring and Summer spill reductions have been possible due to the high efficiency of the Bypass System. (Hemstrom, personal communication, 2010b)

Figure 124: Twin entrances to juvenile bypass surface collector, forebay Rocky Reach Dam (Courtesy of Chelan County PUD)

Figure 125: Rocky Reach juvenile bypass sampling facility: fish condition and run-timing is monitored. Smolts are also collected for acoustic tagging in survival studies. (Courtesy of Chelan County PUD)

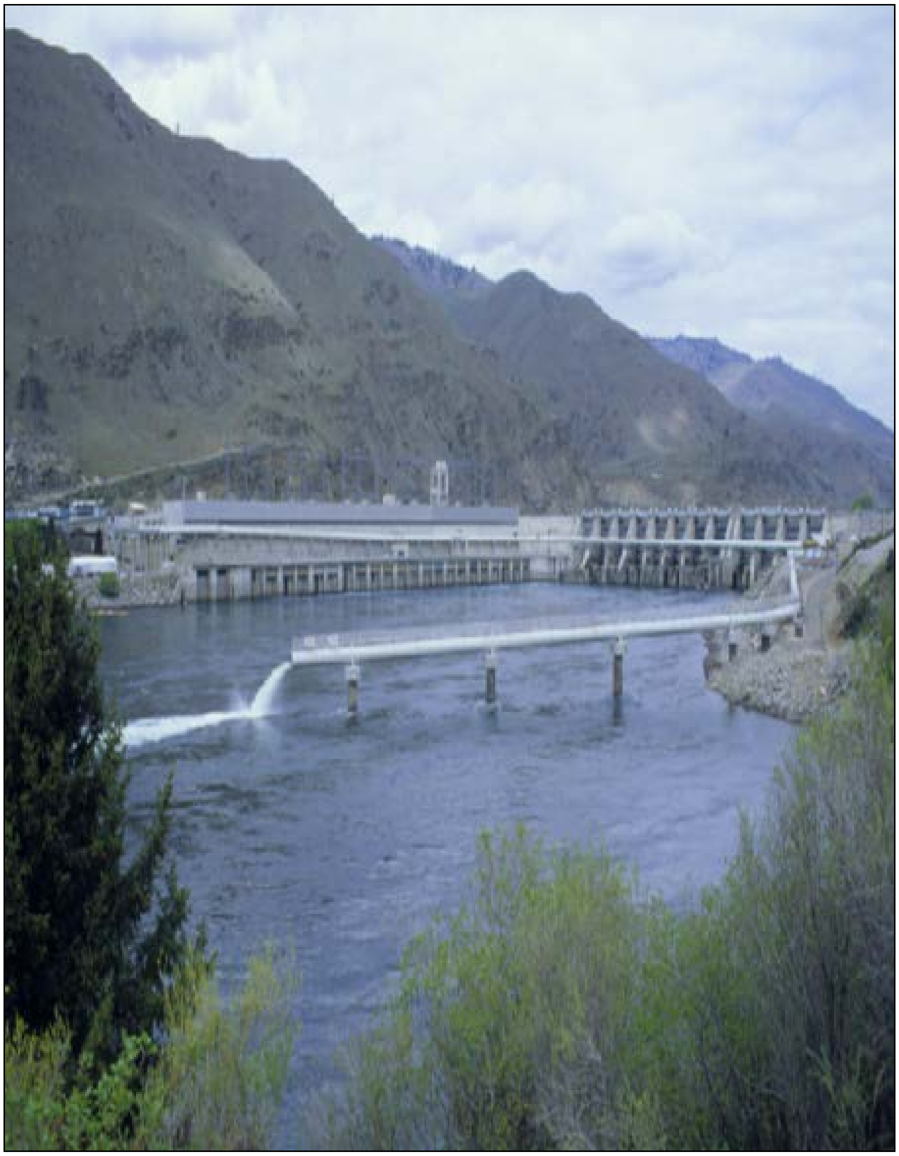

Figure 126: Rocky Reach juvenile bypass conduit (pipe) and tailrace exit (Courtesy of Chelan County PUD)

Figure 127: Close-up of Rocky Reach juvenile bypass system tailrace exit (Courtesy of Chelan County PUD)

According to the Rocky Reach and Rock Island Habitat Conservation Plans (2010 Status Update):

> The Project has surpassed the survival standards for juvenile steelhead, achieving an average of 95.8 percent survival through the entire Project (reservoir and dam) during three annual studies (HCP standard is 93%). Based on these study results and initial bypass efficiency study results for spring Chinook, the Rocky Reach Project is not required to spill in early spring due to passage efficiency of the juvenile bypass system for juvenile spring Chinook and steelhead. Chelan PUD is currently working to complete the three years of survival studies for Chinook and sockeye to achieve the standard [93% Project survival or 95% dam survival]. Chelan PUD operates the bypass system continuously from April 1 to August 31 to accommodate juvenile fish migration and incorporates a 24% level of spill for sockeye passage and a 9% level of spill for the summer migration period. (Chelan County PUD, 2010b)

The "level of spill" refers to the percent of the total river flow that is spilling over the spillway. For example, a 24% level of spill means that 24% of the total river flow is going over the spillway. An email from Hemstrom (Chelan County PUD) on November 5, 2010, clarified that they have actually determined that for sockeye, the 24% spill level actually reduces the efficiency of the surface collector. They conducted studies over 3 years of "spill/no-spill" and determined that a higher proportion of sockeye went into the surface collector during no-spill periods – achieving a higher bypass efficiency (50%). The spillway is located on the opposite side of the river from the surface collector and bypass system. During times of spill, the flow-net pulled fish away from the collector and towards the spillway, typically to the middle of the channel where the only passage is turbines. Due to this issue, the only fish spill required at the dam is 9% of the river flow (per day) for summer-outmigrating Chinook smolts. (Hemstrom, personal communication, 2010c).

A study implemented in 2009 and described in Skalski et al 2010, compared project passage survival and dam passage survival between daytime and nighttime releases of sockeye salmon smolts. During the day, a greater proportion of smolts used the surface collector compared to the powerhouse. At night, a greater proportion of smolts used the powerhouse. Typically, it is believed that fish that pass through the powerhouse would have greater mortality. Although a greater proportion of smolts passed through the powerhouse at night, the total dam passage survival did not decrease compared with daytime values. This was due to greater powerhouse passage survival at night. The authors suggested that the higher powerhouse survival at night could be due to less predation mortality in the tailrace. (Skalski et al 2010)

Another method for downstream passage, as previously mentioned, is using the spillways to pass fish. Since the bypass system has been in place, it has reduced the frequency required to spill water over the dam. Therefore, the spillways are not used to pass fish as frequently as they were historically.

The powerhouse upgrade completed in 2006 also included fish-friendly turbines, so the fish that do pass through the turbines have a better chance of survival than previously.

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Wells Hydroelectric Project

Location: River mile 516 on the Columbia River, Washington, approximately 10 miles northeast of Chelan, WA.

Owner: Douglas County Public Utility District

Dam Name: Wells **Hydraulic Height:** 144' **Year Constructed:** 1967

Target Species: Chinook salmon, sockeye salmon, coho salmon, steelhead

Upstream Passage: Two fish ladders

Downstream Passage: Juvenile bypass through existing spillways, turbines

Description

The Wells Hydroelectric Project is located on the Columbia River in north central Washington State at river mile 516 (Figure 128). Wells Dam is the most upstream dam on the Columbia River that provides anadromous fish passage. Commercial operation began in August of 1967. The project has 10 generators with a total capacity of 840 MW. Douglas County Public Utility District (PUD) completed installation of modern high-efficiency replacement turbine runners on the generators in 1990. The concrete gravity type dam is 160 feet high and 4,460 feet long with 11 gated spillways. It has a unique setup, known as a hydrocombine, where the spillways are located directly above the turbine intakes (Figure 129). The project is operated under a license issued by the Federal Energy Regulatory Commission (FERC) which expires in 2012. The relicensing process is currently underway.

Figure 128: Map of Columbia River Basin Dams (source: USACE)

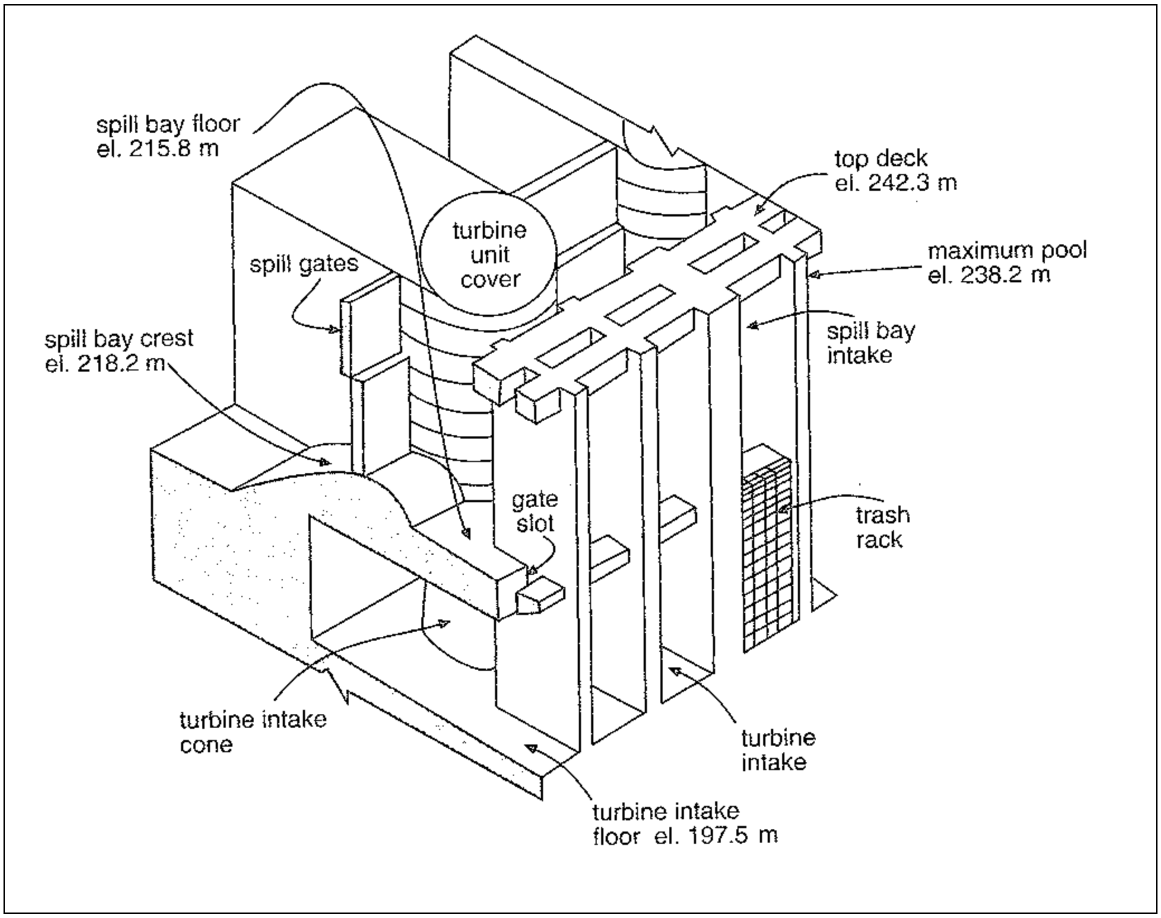

Figure 129: View of Wells Dam hydrocombine configuration (source: Figure 1 in Skalski et al 1996)

Fish Passage History

Wells Dam was built with fish ladders on both ends of the dam to allow for upstream passage of adult salmon and steelhead. Initially, the dam was not built with specific downstream passage facilities. The primary means for downstream passage was through intentional spill through the spillway. In the 1980s, Douglas County PUD developed a bypass system to guide young salmon and steelhead safely through Wells Dam while avoiding the turbines. The system utilized the existing spillways at the project and did not require expensive screens. It was completed in 1989. There is a small percentage of juvenile fish that pass through the turbines instead of the bypass.

In 2004, the FERC approved an Anadromous Fish Agreement and Habitat Conservation Plan (HCP) for the Wells Hydroelectric Project. The HCP consists of a long-term adaptive management plan for species covered under the HCP and their habitats. There is a No Net Impact (NNI) goal in the HCP that consists of two components:

> 1) 91 percent combined adult and juvenile project survival achieved by project improvement measures implemented within the geographic area of the project, and
> 2) 9 percent compensation for unavoidable project mortality provided through hatchery and tributary programs, with 7 percent compensation provided through hatchery programs and 2 percent through tributary programs. (Anchor QEA, LLC and Douglas

> County PUD 2010)

Due to the present difficulty in differentiating between sources of adult mortality, initial compliance with the combined adult and juvenile survival standard will be based on the measurement of 93 percent juvenile project survival or 95 percent juvenile dam passage survival. There is a “phased implementation plan” to achieve the survival standards.

The hatchery located adjacent to Wells Dam was completed in 1967. Its original purpose was to compensate for the loss of fish production upstream of the dam. The hatchery has a 6,100 foot long spawning channel with sections modified to hold adults and juveniles. There are four large earthen rearing ponds, above ground and in ground raceways, and a centralized incubation, early rearing, cold storage and administration building. (Douglas County PUD [date unknown-b])

The hatchery facilities have annual operating costs that exceed $3.5 million. At present time, two types of fish are released from the hatchery. Fish that are released to mitigate for the original construction impacts are known as “inundation fish”. This currently includes releases of: 300,000 yearling steelhead smolts, 320,000 yearling summer/fall Chinook smolts and 454,000 subyearling summer/fall Chinook for inundation compensation. The second type of fish are released for No Net Impact (NNI) purposes, to compensate for direct losses of fish as they migrate through the dam. An equivalent of 3.8% impact (due to 96.2% survival) is used for all stocks. For the NNI hatchery program, this includes releases in the Methow River of: 61,000 yearling spring Chinook smolts, 49,000 yearling steelhead smolts, and 109,000 yearling summer/fall Chinook smolts. Also for the NNI hatchery program, releases occur in the Okanogan River of: 56,000 summer/fall Chinook smolts and 54,000 spring Chinook smolts. In addition, Douglas County PUD is providing proportional funding for 3.8% of the coho reintroduction program in the Methow River. They are also implementing a spawning and incubation flow maintenance program for sockeye that provides 55% survival improvement to compensate for the 3.8% sockeye passage loss on Okanogan sockeye. Although Douglas County PUD are over-mitigating, they do not want to reduce the benefits since the sockeye program is so cost effective. (Bickford 2010b personal communication)

There is also a separate $1 million contract in place that is used for monitoring and evaluating impacts of the hatchery program on wild fish. This includes both positive and negative impacts from hatchery operations. The contract also funds tracking the wild population for baseline response to environmental enhancements and hatchery enhancement. Another component of the monitoring program covers the evaluation of the hatchery facility and staff; determining whether the facility and staff are meeting the program goals established by the HCP Hatchery Committee. This would include evaluating goals for: fish size at release, release numbers, and appropriate genetic crosses. (Bickford 2010c personal communication)

Upstream Passage

To provide passage for adult salmonids, the dam was built with two fish ladders, one on each side of the dam. There are three types of weirs within the ladders. A description of the fish ladders was provided by Shane Bickford of Douglas County PUD:

> The upper section are control weirs with two bottom orifices but no overflow orifices. The middle of the ladder is composed of standard Ice Harbor style orifices that have two bottom and two overflow orifices. The lower section of the ladder that interfaces with the

> tailwater contains Ice Harbor type weirs but with floor diffusers to augment flows within the collection gallery. (Bickford 2010b personal communication)

The upper pools hold more water and are used to control the quantity of water flowing through the lower ladder sections. The typical elevation gain that fish overcome via the ladders is approximately 73 feet. Each ladder contains 73 weirs, thus there is a one foot drop per pool. Velocities at the ladder entrances are 9-10 ft/sec and discharge through each ladder is 48 cfs. It takes the fish 12 to 16 hours to navigate through the ladders. Survival studies have shown over 99% survival for adults (Bickford 2010a personal communication).

The relicensing website for Wells Dam further describes the ladders:

> Each of the two fish ladders has a single entrance for fish, which is located at the bottom of each ladder's collection gallery. Each entrance opens into a collection gallery that is flooded with water in excess of that flowing in the fish ladders. This excess "attraction water" is designed to attract migrating fish into the collection gallery and ultimately into the fish ladder. As fish move up the ladders, provisions for sorting and trapping fish are located adjacent to Pool 40. This area is equipped with a holding box and adult Passive Integrated Transponder (PIT) tag detectors. In addition, the traps are also equipped with slide gates to either retain fish or return them to the ladder. This area is used for brood stock collection, for fish tagging and for other research opportunities. Pool 64 contains facilities for fish counting, including a viewing window, video cameras and a light panel. Pools 67 and 68 are equipped with PIT tag detection devices that interrogates each fish for a PIT tag and, once detected, will record the presence of each tag as the fish ascend the ladders. (Douglas County PUD [date unknown-a])

Downstream Passage

The juvenile bypass system at Wells Dam was completed in 1989 and is currently in operation annually from mid-April through late August. It is the most efficient bypass system on the mainstem of the Columbia River. Five of the eleven spillways, which each have three sections, were modified to create the bypass system. The two outside sections of each spillway are modified with solid steel barriers and the center section is modified with a slotted steel barrier that has a 16 foot wide by 72 feet deep opening (Figure 130). Each bypass bay has a total maximum flow of 2,200 cfs. Attraction flow that keeps fish in the upper part of the water column is created by opening the top section of the gates for each of the five spillways by roughly one foot during bypass operations, when the adjacent generators are operating. Two of the spillways are also setup to allow passage through the ice trash sluiceways or through the bottom spill gates. Pipes are not used in the Wells Dam juvenile bypass system. Since all 11 spillways are required during flood emergencies, the bypass barriers are designed to collapse when the spillway gates are opened more than six feet. (Douglas County PUD [date unknown-c], Bickford 2010b personal communication)

The high volume of flow through the system relative to total discharge, as well as the large size of the bypasses helps contribute to the system's success. The hydrocombine setup of the dam is another reason why the juvenile bypass at Wells is so successful. The spillways are directly above the turbine intakes, which increases the likelihood that juveniles will find a bypass entrance.

The juvenile project survival standard of 93% was initially verified in paired release-recapture studies conducted in1998 to 2000. Project survival is defined as survival through the reservoir, forebay, dam, and tailrace. The three-year average of the independent survival estimates was 96.2%. (Bickford 2010b personal communication)

To aid in the survival of juvenile fish, funding is provided to remove or deter predators. The hazing of avian predators is accomplished using two rotating shifts, seven days per week, that include noise makers and the presence of personnel, trucks, boats and/or dogs. In addition, there are also gull wires in the tailrace to deter avian predators. The total Douglas County PUD annual budget for salmon is $9.6 million. A total of $15 million annually is spent for all fish. The cost of the juvenile bypass system was approximately $2.5 million dollars in 1990. (Bickford 2010a personal communication)

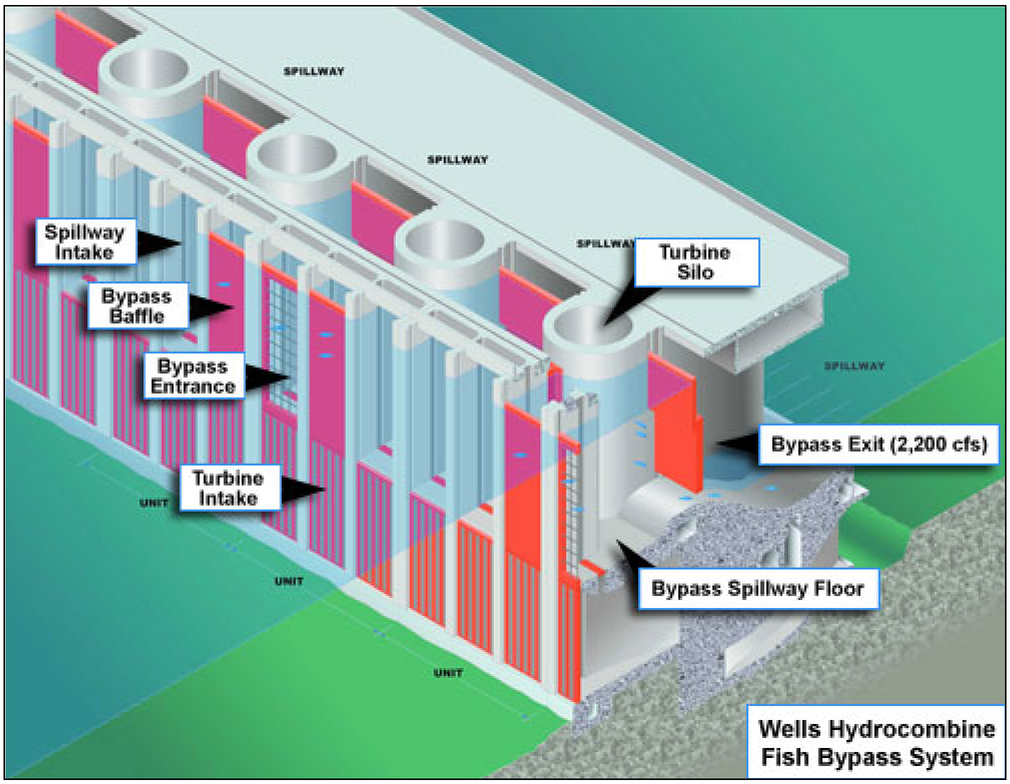

Figure 130: View of Wells Dam Hydrocombine Fish Bypass System configuration (Courtesy of Douglas County PUD)

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Lower Granite Hydroelectric Project

Location: Snake River, Washington. Approximately 70 miles south of Spokane.

Owner: United States Army Corps of Engineers (USACE) Walla Walla District

Dam Name: Lower Granite **Hydraulic Height:** 100’ **Year Constructed:** 1975

Target Species: Chinook salmon, sockeye salmon, coho salmon, and steelhead

Upstream Passage: Fish ladder

Downstream Passage: Bypass system with trap and haul, removable spillway weir

Description

Lower Granite Hydroelectric Project is located on the Snake River in southeastern Washington (Figure 131). It is the fourth dam upstream of the confluence of the Snake and Columbia Rivers and is the most upstream dam on the Snake River to allow upstream migration of salmon and steelhead. Lower Granite Lake extends approximately 39 miles upstream of the dam. Immediately downstream of the dam is Lake Bryan, which is formed by Little Goose Dam, located 37 miles downstream. Lower Granite Dam is a run-of-the-river, concrete, gravity type dam and is roughly 3,200 feet long with an earthfill right abutment embankment. There are eight spillway bays with radial (Tainter-style) gates, each 50 feet wide by 60 feet high. The total length of the spillway is 512 feet long with a peak discharge of 850,000 cfs. One of the spillbays has a removable spillway weir (RSW) installed. There is also a single lift boat lock, 86 feet wide and 674 feet long. The power plant at the dam has six turbine units with a total generating capacity of 810 MW.

Fish Passage History

Lower Granite has had a wide variety of fish passage technologies tested at the dam. The report produced by Battelle in 2009, Synthesis of Biological Research on Juvenile Fish Passage and Survival 1990-2006: Lower Granite Dam, provides a history of fish passage facilities at the dam:

> Fish guidance screens divert a portion of the juvenile migrating salmon entering the turbine intakes away from turbine passage and into the juvenile fish bypass and transportation systems. Lower Granite Dam was the first mainstem Snake River dam to have submerged traveling screens (STSs) included in its original design. In the original system, fish diverted by guidance screens entered a gatewell that included vertical barrier screens (VBSs) to allow for partial dewatering, 8-inch-diameter orifices that led to a collection gallery and additional dewatering structures, and a pressurized pipe at the south end of the powerhouse. The pipe led down the tailrace into a fish and water separator, holding ponds, an evaluation and monitoring facility, a transport loading dock, and an outfall. Fish entering the facility could either be returned to the river through the outfall or loaded into barges for transportation downstream.
>
> In the 1980s, the juvenile bypass and transportation systems were overhauled. New-generation STSs were installed, the gatewell orifices were increased to 10-inch diameters, the dry fish/water separator was replaced by a wet separator, and additional raceways were installed. In the 1990s, emergency gates were raised from their storage positions in the gatewells in a successful effort to improve the number of fish guided into the bypass system. In 1996, the STSs were replaced with new extended-length submersible bar screens (ESBSs) and new VBSs were installed in the gatewells. A prototype surface bypass and collector (SBC) was installed in 1996 in front of turbine units 4, 5, and 6 [Figure 132] to test surface passage concepts. The SBC was a fish-collection channel with four upstream-facing entrances and a single outfall located at spillbay 1. It was 18 meters (59 feet) high, 6 meters (19.7 feet) deep, and 100 meters (328 feet) long and had large flotation chambers so that it could move vertically as forebay elevations changed. The configuration of the SBC changed over several years of testing and development, but the structure was not intended to be a complete, permanent or final design. In 1998, the simulated Wells intake (SWI) was fitted to the bottom of the SBC. The purpose of the SWI, which extended the bottom of the SBC by 6 meters (19.7 feet), was to reduce the downward flow near the SBC (i.e., within 30 meters [98 feet]) and allow the fish to find the SBC entrances. During 1998, a prototype behavioral guidance structure (BGS) was deployed to divert fish away from the south powerhouse (turbine units 1–3) and direct them toward the SBC. The BGS was a steel wall 335 meters (1100 feet) long that extended from the south end of the SBC (near turbine unit 4) upstream to within 20

> meters (66 feet) of the south shore. The BGS was 24 meters (78 feet) deep where it attached to the SBC and tapered to a depth of 17 meters (56 feet) at its upstream end. The prototype BGS did not extend to the upstream shoreline, but the plan was to close that gap in the final implementation. To provide a surface passage route for juvenile fish, an RSW was installed in 2001 at Lower Granite Dam. The SBC structure was removed in 2003. After removal of the SBC, a new BGS attachment point was added between turbine units 5 and 6 (Figure 2.2). The BGS also was reduced in depth at the downstream end to a maximum of 17 meters (55 feet) instead of 24 meters (78 feet). Table [1] lists fish passage improvements to Lower Granite Dam from 1990 through 2006.
> (Battelle 2009)

A general site plan for Lower Granite Dam’s current configuration can be seen in Figure 133.

Figure 131: Map of Columbia River Basin Dams (source: USACE)

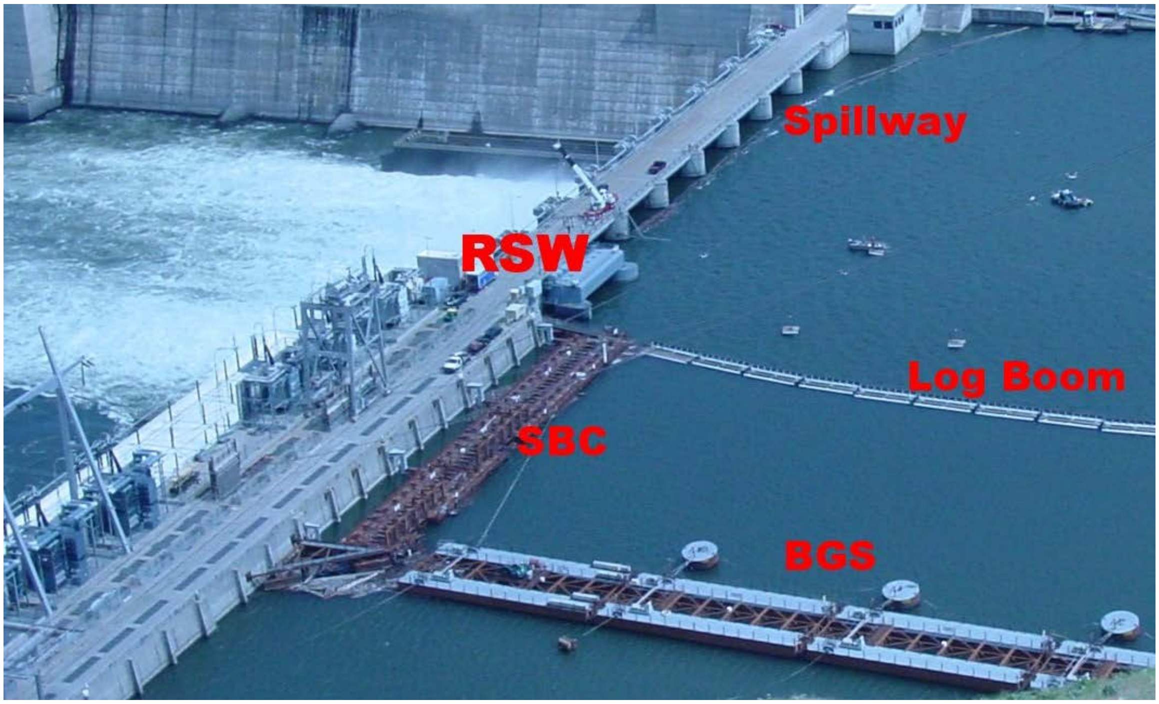

Figure 132: Photograph displaying Lower Granite Dam's major fish passage structures (note: This is not the current configuration) (source: Battelle 2009, prepared for USACE)

Table 1. Fish passage improvements made at Lower Granite Dam from 1990 through 2006

Year	Modification	Purpose
1990s	Raised emergency gates from storage positions	Improve the number of fish guided into the bypass system
1991	Increased gatewell orifice size to 10 inches	Increase flow from gatewell to bypass channel
1991	Added new lab, office, raceway, roof, bypass outfall	Support fish studies, improve holding conditions, and improve survival of bypassed fish
1995	Installed and evaluated the first sort-by-code system	Allow individual PIT-tagged juveniles to be sampled or examined
1995	Installed the first 2-way and 3-way fish diversion gates at Lower Granite Dam	Allow individual PIT-tagged juveniles to be sampled or examined or diverted back to the river
1996	Installed new ESBSs and VBSs to replace STSs	Increase fish guidance efficiency and reduce fish stress and injury in bypass system
1996	Constructed SBC in front of turbine units 4, 5, and 6	Collect juvenile salmonids that would otherwise have passed into turbine units 4-6
1998	Modified SBC (SWI retrofitted to the bottom of the SBC and BGS attached to south end of SBC)	Decrease passage through turbines and increase probability of collection in the SBC
2000	Make PIT-tag sort-by-code improvements	Decrease stress on juvenile salmonids
2000	Retrofitted BGS entrance to SBC with shaped steel sections	Smooth the flow of water entering the SBC to increase the number of fish entering the SBC
2002	Installed RSW at spillbay 1 and removed SBC outlet	Provide surface passage route, improve spillway passage proportion for a given proportion of spill, and decrease forebay delay
2003	Removed SBC and placed BGS in storage location	Conduct maintenance

2005	Installed fish-tagging facility	Improve the ability to conduct studies of fish
2006	Attached a reduced-depth BGS between units 5 and 6 for testing	Divert fish from turbines 1-5

Source: Battelle 2009, prepared for USACE.

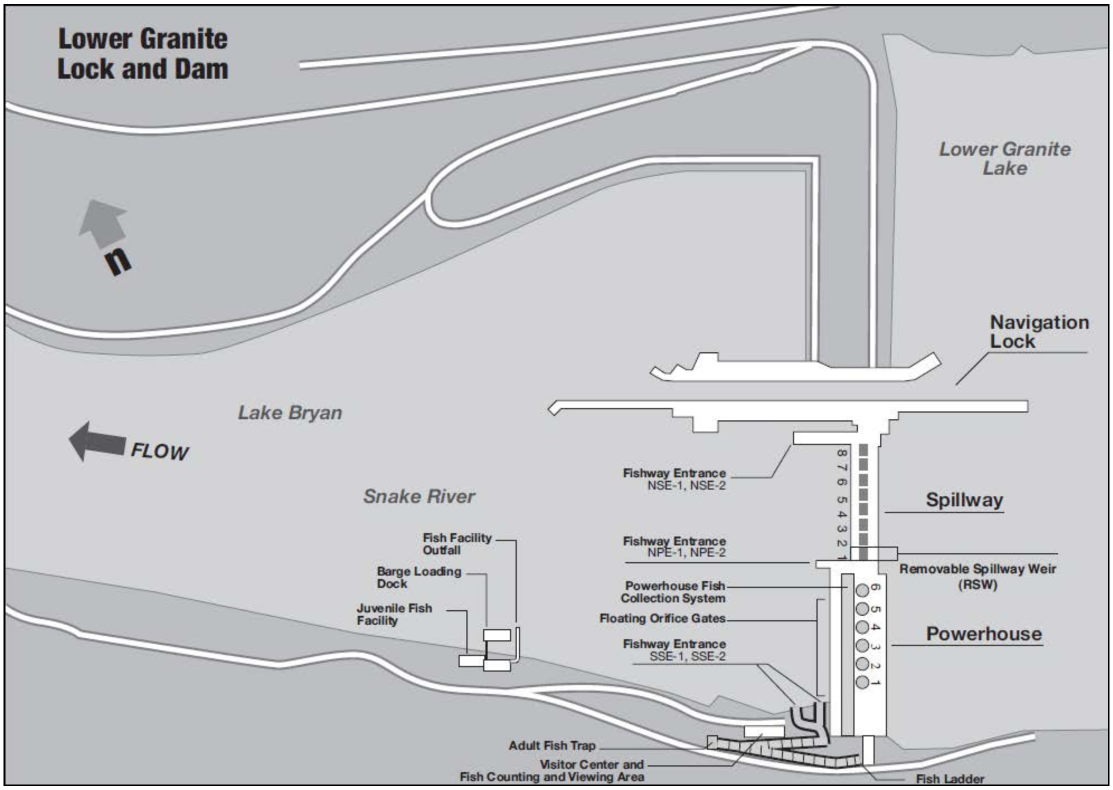

Figure 133: Lower Granite Lock and Dam general site plan (source: USACE)

Upstream Passage

The primary method for upstream passage at Lower Granite Dam is via a fish ladder located on the south shore. There are two entrances to the ladder (Figure 133). The slope of the ladders varies from 1V: 10H to 1V:32H. The design capacity of the ladder is 75 cfs. There are 3 pumps to produce attraction water with a capacity of 3,150 cfs. A description of the adult fish facilities is found in the USACE Final 2010 Fish Passage Plan:

> The adult fish passage facilities at Lower Granite are made up of one fish ladder on the south shore, two south shore entrances, a powerhouse collection system, north shore entrances with a transportation channel underneath the spillway to the powerhouse collection system, and an auxiliary water supply system. The powerhouse collection system is comprised of four operating floating orifices, two downstream entrances and one side entrance into the spillway basin on the north end of the powerhouse, and a common transportation channel. Four of the floating orifices and the two downstream entrances at the north end of the collection system are operated. The north shore entrances are made up of two downstream entrances and a side entrance into the spillway basin with the two downstream entrances normally used. The auxiliary water is supplied by three electric pumps that pump water from the tailrace. Two pumps are normally used

to provide the required flows. (USACE 2010a)

Most of the upstream passage facilities can be seen in Figure 133. In 2003, PIT tag detectors were installed on four weirs in the upper section of the ladder. Figure 134 shows the fish ladder during antenna installation and Figure 135 shows the ladder post-installation when the ladder is operational.

Figure 134: Lower Granite Dam Fish Ladder: Vertical slot and weir orifice antennas during installation (Courtesy of PTAGIS)

Figure 135: Lower Granite Dam Fish Ladder: Vertical slot and weir orifice antennas after installation, when the ladder is operational (Courtesy of PTAGIS)

For the fish passage period (March 1 through December 31), a few of the operating requirements listed in the USACE Final 2010 Fish Passage Plan include:

- Water depth over ladder weirs: 1' to 1.3'
- Head on all fishway entrances: head range: 1' to 2'
- Channel velocity: 1.5 fps to 4 fps
- Lights in the tunnel under the spillway need to be on

Downstream Passage

For downstream passage at Lower Granite Dam, current facilities consist of a bypass system with transportation facilities, as well as a removable spillway weir. The transportation program includes collecting juvenile anadromous fish at Lower Granite Dam, Lower Monumental Dam, and McNary Dam, transporting them by barge or truck, and releasing them below Bonneville Dam on the Columbia River. The Lower Granite Lock and Dam Juvenile Fish Facility Upgrade, Engineering Design Report, March 2010, provides a description of the existing juvenile collection and transport system:

> The existing juvenile fish sorting and holding facilities are located downstream of the dam on the south shore. Juvenile fish enter the bypass system through 18 bulkhead slot orifices located in the upstream powerhouse intake bulkhead slots. There are 2 orifices in each bulkhead slot for a total of 36. Only one orifice per bulkhead slot is operated at a time. Fish that are guided away from the turbines into the bulkhead slot pass through the orifices and into a collection channel. The channel is about 551 feet long.
>
> Existing collection gallery orifices are 10-inch-diameter and nominally discharge 6 to 11 cubic feet per second (cfs). The typical center line elevation of the orifices is at 729 feet mean sea level (fmsl) under 4 to 9 feet of head. Flow through the orifices varies with forebay elevation. Pipe elbows deflect the orifice discharge and fish into the collection channel. At the north and south ends of the collection channel, two water add-in features supplement orifice flows to bring total flows up to about 225 cfs.
>
> Downstream of the collection channel, flows enter a downwell that is 6 feet wide by 15 feet long by about 20 feet deep. At the bottom of the downwell a 42-inch diameter transportation pipe carries transportation water and fish approximately 1,700 feet downstream to the holding and loading facilities.
>
> At the holding and loading facility, the fish upwell into a large head tank and pass through a fish separator. The juvenile fish are separated from the larger adult salmonids, non-salmonids, and debris. From the separator, the fish can be directed to raceways for holding, to a barge, to a sample tank for counting and/or marking, or back to the river. From the raceways, the fish can be loaded into trucks or barges or released to the river through the barge loading boom. Excess transportation water is used to supply water to the holding and loading facility with the remainder returned to the river. (USACE 2010b)

Although it is not mentioned above, the bypass system uses extended length submersible bar screens with flow vanes and improved modified balanced flow vertical barrier screens to help guide fish into the orifices. The bypass also has PIT tag antennas located throughout the system.

The USACE Engineering Design Report also discusses possible modifications to the facility that would improve conditions for juvenile steelhead trout and salmon:

> Future hydrosystem performance, as discussed in the National Marine Fisheries Service's (NMFS) latest Biological Assessment in August 2007, as well as in other documents, will be tracked and evaluated through adult reach survival and juvenile dam survival performance standards, and through a juvenile system performance target. The upgrades at the Lower Granite juvenile fish facilities will reduce stress, injury, delay, and predation, which should increase both dam and system performance. Even minor improvements, particularly related to indirect project survival, transport, and delayed mortality, may dramatically increase smolt-to-adult returns (SAR). New features being added to this facility also have the potential to significantly increase kelt returns.
>
> The estimated construction cost for the upgraded facilities (assuming minimal provisions are provided for a future SBC and that collection channel bulkhead slot fish passage weirs are incorporated into the design) is $45,161,125. The facilities are expected to be operational within 2 years once funding becomes available for construction. (USACE 2010b)

A USACE PowerPoint presentation, lists some of the specific upgrades:

- Larger collection channel and orifices / Possible overflow weirs
- New primary dewatering with automated cleaning systems
- Open channel main facility / bypass transport flume
- Updated PIT tag technology with improved full flow bypass
- Kelt holding, release, and transport facilities
- Lamprey considerations
- Improved separator
- Holding facility improvements (e.g. adult debris separator, flumes, sampling, etc.)
- Raceway improvements
- New barge dock and loading facilities
- Improved outfall pipe locations
- Reuse excess water to supplement adult fishway/trap
- Surface bypass collector minimal provisions
  (USACE 2010d)

Voluntary spill through the spillway is used at Lower Granite Dam to help achieve desirable conditions for upstream fish passage in the tailrace, as well as to increase the percentage of downstream migrating fish to pass via the spillway instead of through the turbines.

In 2001, a removable spillway weir (RSW) was installed at Lower Granite Dam. The RSW is a spillway modification that allows fish to pass over an elevated spillway crest, as opposed to passing under the usual gates that open well below the water surface. Since fish are generally surface oriented, the RSW provides better attraction flow. During large flood events, the RSW can be lowered to the bottom of the forebay. Figure 136 displays a photograph of the RSW, prior to installation at Lower Granite Dam. The Removable Spillway Weirs section of this report provides more details on operation of RSWs.

Figure 136: Removable Spillway Weir, before installation at Lower Granite Dam (source: USACE)

For Lower Granite Dam, route specific survival rates were measured in 2005 and 2006. For yearling Chinook salmon and steelhead passing the spillway, removable spillway weir, or juvenile bypass system, rates were usually greater than 95%. The survival for the same groups passing through the turbines was usually near 90%. For subyearling Chinook salmon, the survival rates varied from 92% to 97% passing the removable spillway weir, to 84% to 93% for those passing the spillway or juvenile bypass system. The rates varied from 68% to 87% for subyearling passing through the turbines. (Battelle 2009)

Dam survival rates are already high in the spring, and the only route with a potential improvement in survival is turbine passage. During the summer, the RSW provides the highest survival rates, but there is room for improvement in all passage routes (Battelle 2009).

The 2009 Battelle report has more information regarding further studies including: fish distribution and movement in the forebay, evaluation of transportation, fish guidance efficiency of screens, and direct injury evaluation of surface passage.

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United States — Oregon

Carmen-Smith Hydroelectric Project

Location: McKenzie River, Oregon, approximately 50 miles east of Eugene and 77 river miles upstream of its confluence with the Willamette River (Figure 137).

Owner: Eugene Water and Electric Board

Dam Name: Trail Bridge **Hydraulic Height:** 86’ **Year Constructed:** 1963

Target Species: Spring-run Chinook salmon, bull trout, coastal cutthroat trout, Pacific lamprey

Upstream Passage: Currently in the design process on a vertical slot fish ladder

Downstream Passage: Currently in the design process on a floating fish screen, attached to a new vertical intake pipe, with a piped bypass

Project Description

The Carmen-Smith Hydroelectric Project (Project) is operated by the Eugene Water and Electric Board (EWEB), whose 50-year Federal Power Commission (Federal Energy Regulatory Commission) license expired in 2008. EWEB is seeking a new, 50-year operating license from the Federal Energy Regulatory Commission (FERC), which is expected to be issued in 2010. The Project was completed in 1963 and consists of three dams, Carmen Diversion, Smith, and Trail Bridge (Figure 138).

The 25-foot-high Carmen Diversion Dam on the McKenzie River holds back Carmen Reservoir, which has little storage volume and is mainly used to divert water to the Smith Reservoir on the Smith River. Smith Reservoir water, stored behind the 235-foot-high Smith Dam, is routed through the Smith Power Tunnel to two turbines at the Carmen Power Plant, which discharges into the Trail Bridge

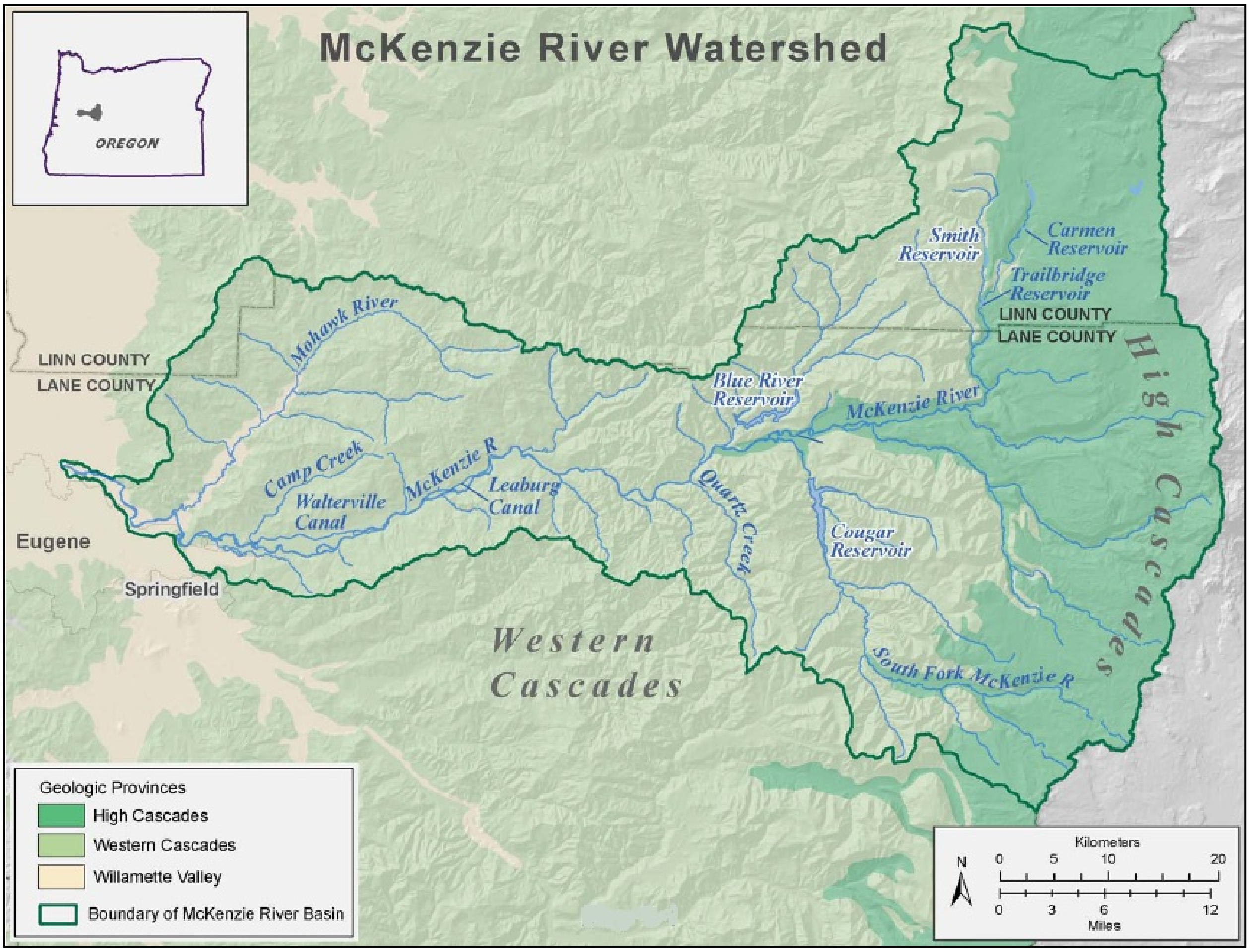

Figure 137: McKenzie River Watershed (Courtesy of EWEB)

Reservoir on the McKenzie River. The Carmen Power Plant is the main power plant for the Project and can generate up to 104.5 MW of electricity. The Carmen Power Plant operates in a peaking mode, while the Trail Bridge facilities operate as a re-regulating facility. The Project operates so that on an average daily basis, inflows into Smith and Carmen reservoirs are roughly equivalent to the outflow through Trail Bridge Dam into the McKenzie River below the dam (EWEB 2006).

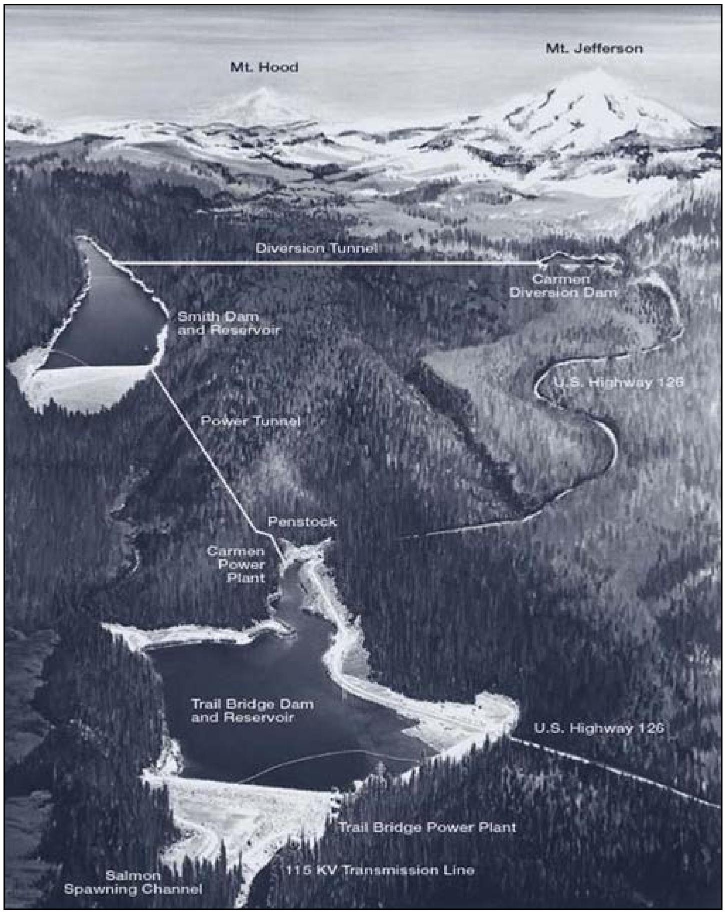

Figure 138: Carmen-Smith Hydroelectric Project (Courtesy of EWEB)

Trail Bridge Dam is comprised two distinct sections, the main dam section with a gated spillway and power plant, and a saddle dam with an emergency spillway (Figure 139). Both the main dam and saddle dam are earth fill structures, with the emergency spillway having an articulated concrete armor. The main dam rises approximately 100 ft above the historical McKenzie River channel, with the saddle dam about 9.5 feet lower. The maximum hydraulic height of the dam is 86 feet, from full pool elevation to the powerhouse tailrace elevation. The gated 30 foot wide spillway for the main dam is 41.5 feet below the dam crest and has a capacity of 28,300 cfs at the probable maximum flood. The emergency spillway section has a capacity of 25,000 cfs at the probable maximum flood. A power plant is located at the toe of Trail Bridge Dam and its penstock is capable of passing up to 2,000 cfs to power a single Kaplan turbine, generating as much as 10 MW. Trail Bridge reservoir is relatively small, approximately 900 feet wide by 2700 feet long, with a capacity of 2,060 acre-feet at full pool. The maximum reservoir fluctuation is 12 feet (EWEB 2006).

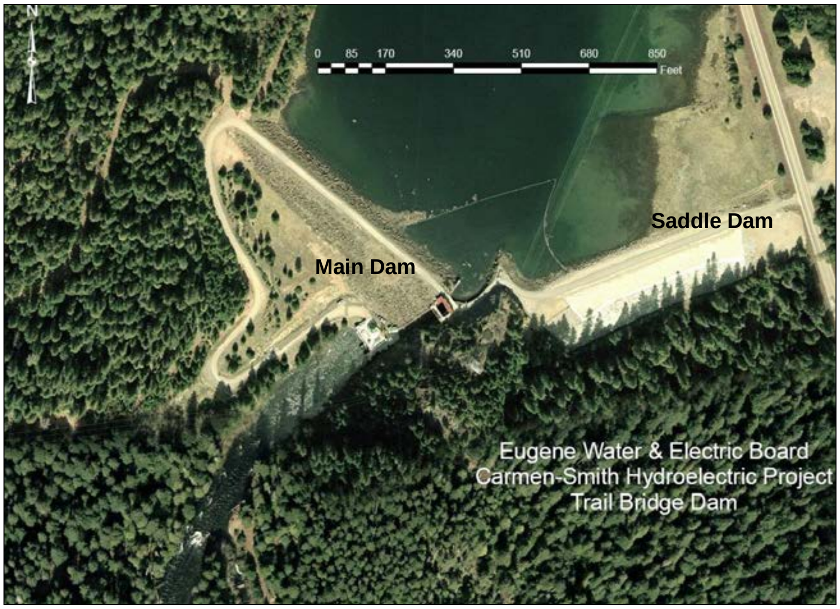

Figure 139: Aerial Photo of Trail Bridge Dam (Courtesy of EWEB)

Fish Passage History

From the Project's inception it has not had fish passage at any of the dams. In 1962, a spawning channel was constructed downstream of Trail Bridge Dam, under agreement with the Oregon Fish and Game Commission, to provide spawning habitat for returning Chinook salmon (EWEB 2006).

In October 2008, EWEB signed a Settlement Agreement with 6 State and federal agencies, 3 Native American tribes, and 7 environmental and recreation groups on the enhancements and other improvements EWEB will undertake as part of its new operating license. For this paper, we will concentrate on the fish passage requirements at Trail Bridge Dam.

From the Settlement Agreement, EWEB are required to design, construct, operate, and maintain a volitional fish ladder and tailrace barrier at Trail Bridge Dam. In addition, EWEB will develop the fish ladder and tailrace barrier consistent with NMFS criteria and guidelines. EWEB has committed to significant design features beyond the NMFS requirements, including nine-inch fish ladder steps to enhance passage for native salmonid species other than Chinook salmon and bull trout and components designed to allow passage of Pacific Lamprey (if present).

For downstream passage, the Settlement Agreement states that EWEB will construct, operate and maintain a fish screen and bypass system for downstream passage at Trail Bridge Dam. EWEB will design the screen and bypass system to screen fish at all power plant flow rates and to be consistent with current criteria.

Current Fish Passage at Trail Bridge Dam

EWEB has developed conceptual designs for volitional upstream and downstream passage at Trail Bridge Dam. Outside of passing fish, the main objectives of the fish passage alternatives for this site are to not breach the dam core to build the ladder and downstream bypass and to have a gravity flow system (Andrew Talabere, Personal Communication, July 16 2010).

Upstream Passage

In their Fish Passage Technical Report (2006), MWH and Stillwater Sciences considered two upstream fish passage options, trap-and-haul and a fish ladder.

The trap-and-haul option would use the existing spawning channel tailrace barrier to guide returning adults into an entrance pool and then into a short section of a Denil-type fish ladder. At the top of the Denil ladder, the fish would then move over a false weir and into a holding pool and pond. The fish would be crowded into the holding pool from the raceway, removed from the holding pool with a fish hopper, and loaded into a fish transport truck for transport to the reservoir.

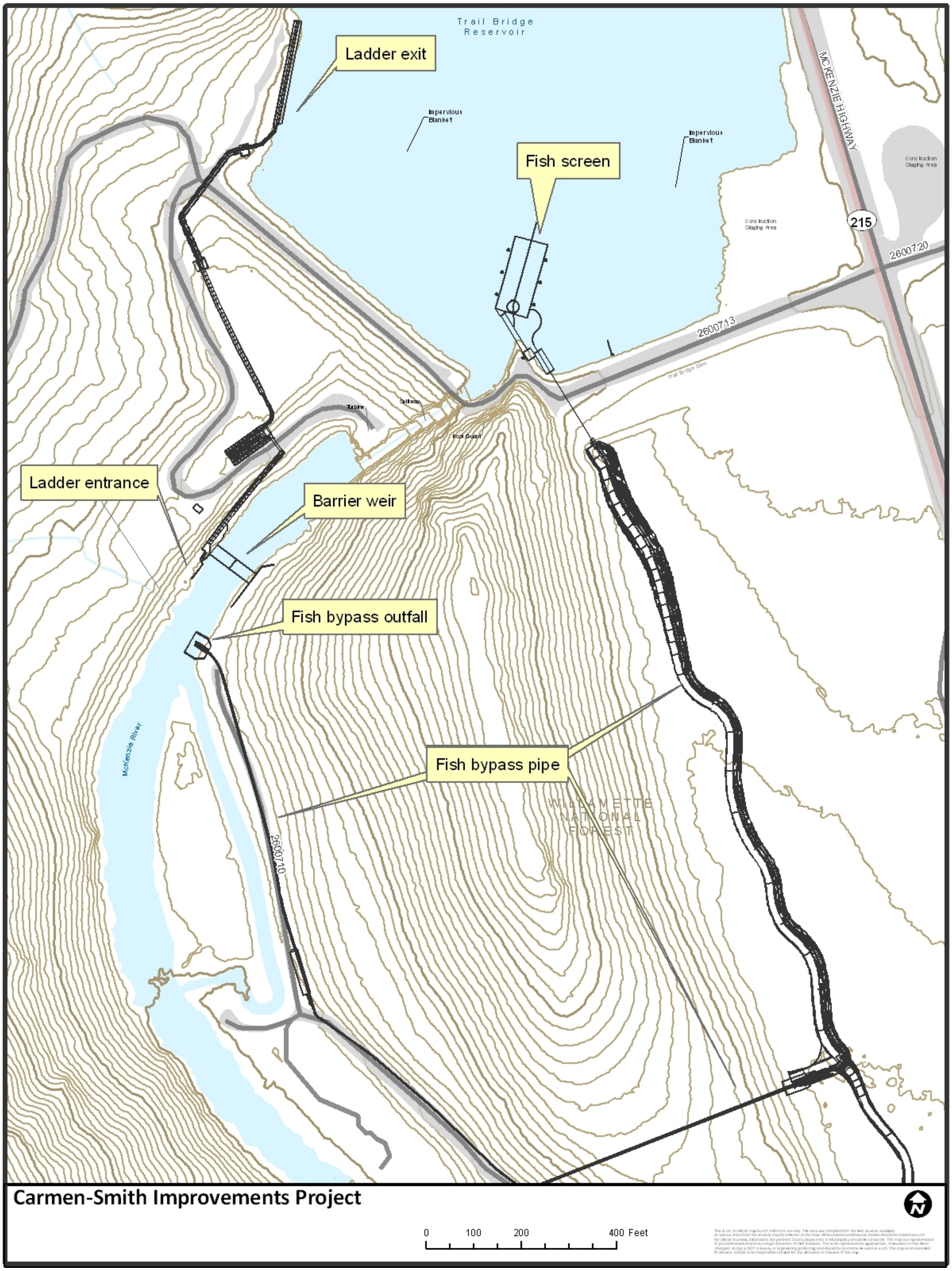

Figure 140: Trail Bridge Dam Fish Passage Facilities (Courtesy of EWEB)

The ladder option would use a vertical slot fish ladder, with a couple of different routing alternatives.

The authors do note that a Half Ice Harbor fish ladder could be used for all of the ladder option routings. The routing alternatives use ladder entrances on either the right or left bank and incorporate fish transport channels (concrete flumes set at a shallow gradient), since the routings are longer than the ladder alone would provide. One alternative included 3200' of constructed natural channel sandwiched between three ladder sections and two concrete transport channel sections. However this option was deemed too risky compared with a more traditional fish ladder and was therefore never seriously considered. MWH also developed fish passage options for 235' high Smith Dam, but passage was not required and never seriously considered (Andrew Talabere, Personal Communication, July 24, 2010).

A vertical slot ladder was chosen as the preferred alternative to provide volitional upstream passage of adult anadromous and resident fish, including spring-run Chinook salmon, bull trout, coastal cutthroat trout, and Pacific lamprey (Andrew Talabere, Personal Communication, November 2, 2011). The ladder entrance will be on the right bank of the river just downstream of a new tailrace barrier weir (Figure 140). The ladder will gradually climb the right bank and parallel the river, and then turn left towards the right dam abutment. Fish will pass around the abutment and clay core in a concrete transport channel before reaching the exit control structure.

The ladder will consist of pools and transport channels, and is designed to overcome a maximum of 86 feet of water surface differential between the reservoir at full pool and the river downstream of the new tailrace barrier. The ladder has slots that are 12" wide, 3" X 4" orifices for Pacific lamprey, and a 9" water surface elevation difference between each pool to accommodate non-anadromous (resident) fish. The number and configuration of the pools is still to be determined, but the types of pools which may be used have been determined. The majority of the 116 pools will be standard size (8'W X 9'L), with every 10th pool being an 8'W X 13.5'L resting pool. Within the ladder there will also be several hundred feet of transport channel, constructed of concrete in a rectangular cross-section (4'W with a design water depth of 4.33'). The velocity in the transport channels will be 1.5 fps and the current design flow for the ladder is 26 cfs. The transition pools at each end of a transport channel will range in size between the typical pool and resting pool depending on whether they a transitioning to or from the transport channel or if they are on a corner. The 16 exit pools are currently designed with 45 degree beveled gates that exit into the reservoir. (Andrew Talabere, Personal Communications, October 20, 2010 and November 16, 2011).

Downstream Passage

Downstream migrants, both juveniles and adults, will be moved downstream through a fish screen and bypass system. One of the requirements of the system is that it must be able to pass bull trout as large as 36" in length. EWEB will use a floating fish screen structure attached to a new vertical intake pipe which will accommodate the 12 feet of reservoir fluctuation (Figure 141). The floating screen structure will have two bays which will screen the maximum full intake flow of 2,000 cfs (Figure 142). Screening the full intake flow was chosen to eliminate the need for guidance netting, which would have eliminated up to a 1/3 of the reservoir from recreation, and to avoid years of monitoring and potential adaptive management (Andrew Talabere, Personal Communications, August 24, 2010 and November 16, 2011).

After passing the screens, the two bypasses will combine into one and the fish and 30 cfs of water will be piped through an articulating transfer pipe and into the bypass system. The bypass pipe will go through the saddle dam and then will travel approximately 3,800 feet to the McKenzie River just downstream of the barrier weir. The bypass pipe will be mainly high density polyethylene and velocities in this type of pipe will range from 9.7 to 12.7 feet per second. There will be also be two sections of corrugated metal pipe set at a 6% slope that will flow at 11.4 feet per second. Fish will also pass through a 350-foot-long tunnel bored through bedrock (Andrew Talabere, Personal Communication, November 2, 2011).

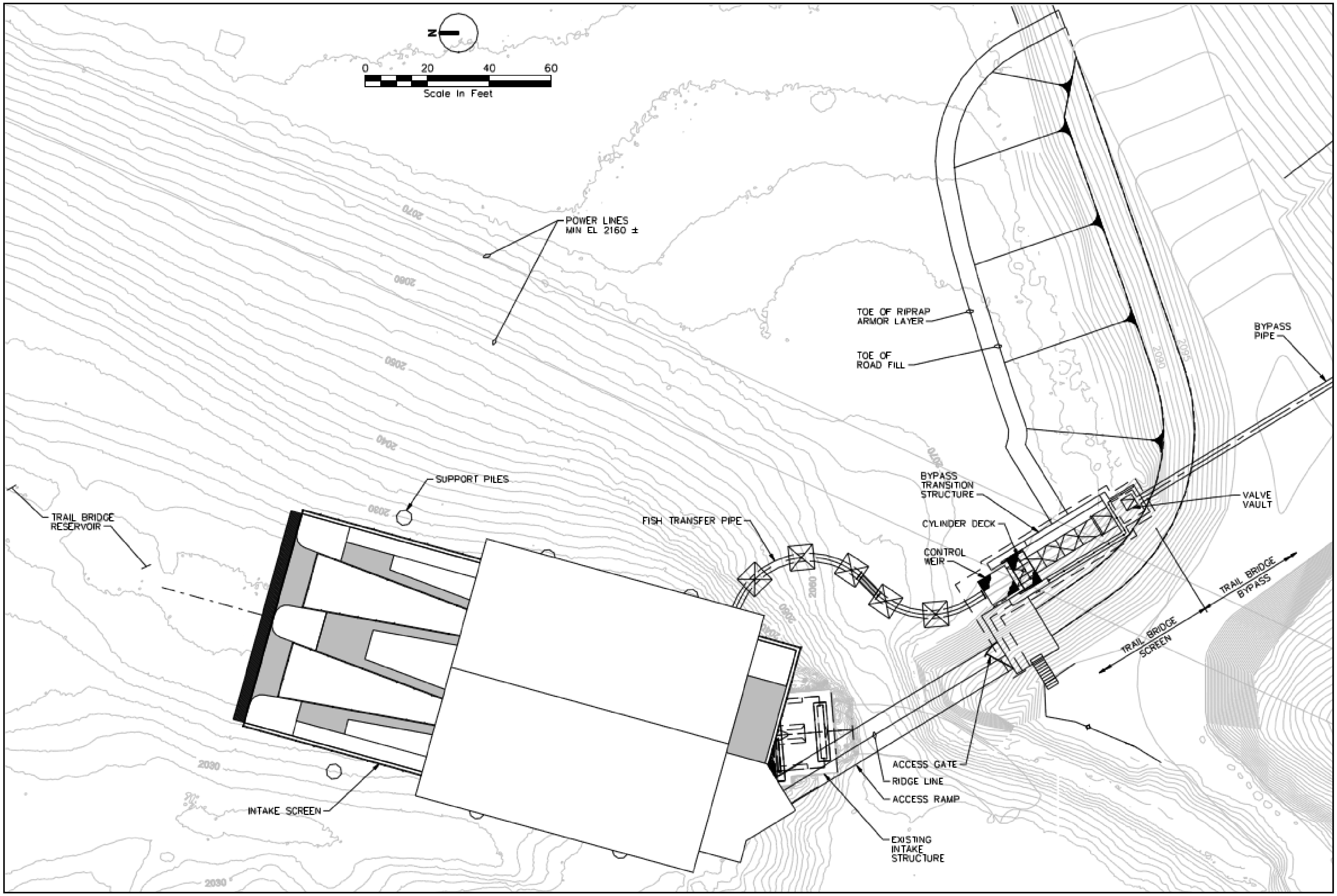

Figure 141: Downstream Migrant Collection and Bypass Facility (Courtesy of EWEB)

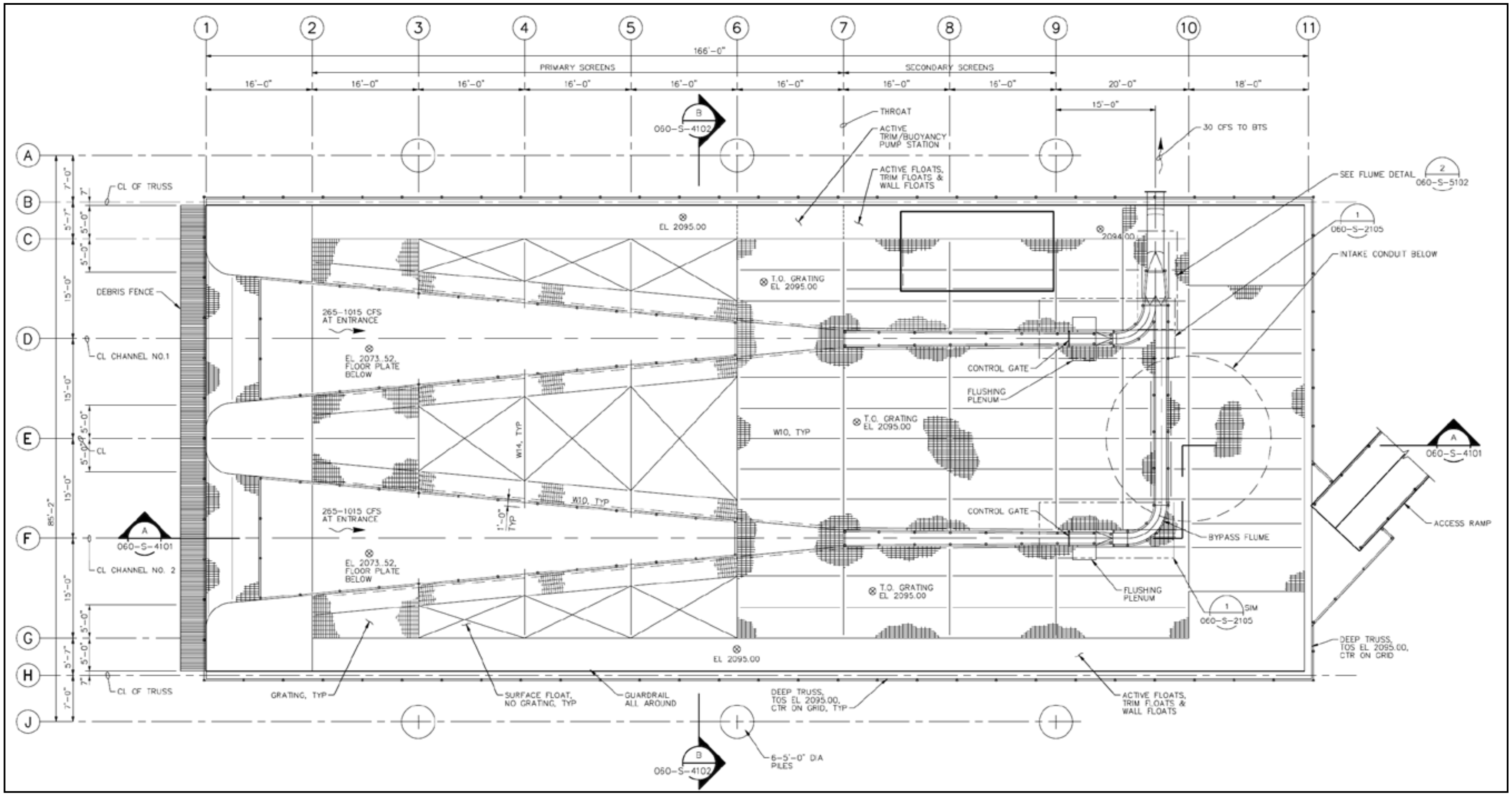

Figure 142: Fish Screen Structure (Courtesy of EWEB)

At Trail Bridge Dam, there are no downstream water temperature issues, as with the Cougar Project on the South Fork McKenzie River. Specifically, EWEB are not concerned about taking the intake water from near the surface of the reservoir and possibly affecting downstream river temperatures because the river at the project site is more than 80% spring fed and remains at a near constant temperature year round (Andrew Talabere, Personal Communication, August 24, 2010).

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Cougar Hydroelectric Project

Location: South Fork McKenzie River, Oregon, 42 miles east of Eugene and approximately 4 miles upstream of the confluence with the mainstem McKenzie River

Owner: United States Army Corps of Engineers

Dam Name: Cougar **Dam Hydraulic Height:** 467’ **Year Constructed:** 1964

Target Species: Mainly spring-run Chinook salmon and bull trout, but also coastal cutthroat trout, Pacific lamprey, and resident rainbow trout

Upstream Passage: Collection and Transport

Downstream Passage: Currently, fish pass through the turbines or regulating outlet. The U. S. Army Corps of Engineers are evaluating alternatives for a downstream passage facility.

Description

Between 1941 and 1968, the U. S. Army Corps of Engineers (USACE) constructed, and now operates, a system of 13 dams and reservoirs in the Willamette River drainage system (Figure 143). Most of the Willamette Valley Flood Control Project dams are "high head" and more than 250 feet tall. Their primary purpose is to provide critical flood damage reduction for the entire Willamette Valley, including the cities of Eugene, Salem and Portland. The projects provide some hydroelectric generation (about 180 megawatts annually), along with recreational and fishing opportunities, water quality benefits, and municipal and irrigation water. Most of the dams do not include fish passage, and those that do are not

Figure 143: The Willamette Basin (Courtesy of USACE)

Figure 144: Cougar Dam and Reservoir (Courtesy of USACE)

very effective at passing fish. In March 1999, NOAA's Fisheries service listed upper Willamette River Chinook as threatened under the Endangered Species Act (NMFS 2009).

One of the dams constructed was Cougar Dam (Figure 144), located on the South Fork McKenzie River approximately 42 miles east of Eugene and 4 miles upstream of the confluence with the mainstem McKenzie River. The 519-foot-tall (structural height) rock-fill embankment dam was completed in 1963 and holds back the 6.5-mile-long, 219,000-acre-foot Cougar Reservoir. The power plant penstock and the regulating outlet are both fed by the same intake structure, with the regulating outlet intake 60 vertical feet above the penstock intake. The 13.5-foot-diameter regulating outlet releases water down a steep, 225-foot-high outlet chute (Figure 145). As much as 13,500 cfs can be released through the regulating outlet and 76,140 cfs over the spillway with the reservoir at maximum pool elevation. In addition, up to 1,050 cfs can be run though the 2 turbines of the power plant, located at the downstream toe of the dam, generating as much as 25 MW. Generally, the reservoir is operated mainly for flood control and water storage, with low water surface elevations in the winter, filling operations February though May, and release of conserved water May through November. The target elevation for the reservoir in winter is about 160 feet below the maximum conservation storage elevation (CH2M Hill 2000).

After the dam was built, water temperature issues below the dam caused problems for returning adults. The river was too warm in the winter and too cold in the summer. The USACE completed the addition of a water temperature control (WTC) structure to their existing intake in December 2004 to alleviate this problem. Gates in front of the regulating outlet and penstock maintain the flow capacity of the intake structure and selectively withdraw water from different elevations in the reservoir to meet target outflow temperatures. Flow distribution decisions are based on reservoir outflow and data from temperature instrumentation on the face of the intake structure. The gates can be opened to varying degrees to allow a proportion of flow from different levels (USACE et al 2007).

In 2010, the USACE finished building an adult collection, holding, and transfer facility below the dam in the power plant tailrace that will allow biologists to collect adult fish from the river and transport them upstream of the dam during spawning season (described in detail in the Current Fish Passage section).

Figure 145: Regulating Outlet (CA Dept. of Water Resources)

Fish Passage History

The most abundant sub-population of natural origin Chinook salmon in the Upper Willamette Basin is sustained by the McKenzie River (USACE 2010). Historically, an estimated 4,000 spring-run Chinook returned to the South Fork McKenzie annually. The construction of Cougar Dam has blocked fish passage to approximately 16 % of the historical spawning habitat in the entire McKenzie basin, with this habitat being some of the best in the basin (ODFW 2005 in NMFS 2008). In addition, recent estimates indicate that greater than 90% of South Fork McKenzie Chinook spawning habitat is located above Cougar Dam (R2 Resource Consultants, Inc. 2009 in USACE 2010).

Spring-run Chinook fish passage facilities were constructed at the time the dam was built, but have not been operated since the late 1960s. For upstream passage, a collection and transport system was used, and for downstream passage, a bypass system was constructed on the intake tower. Both systems were ineffective and were discontinued in the late 1960s (Ingram and Korn 1969).

The upstream collection and transport system began with a fish trap (permanent trap), installed to collect salmon in the tailrace channel about 200 yards downstream of the power plant. A rack was constructed across the tailrace channel to divert the adult migrants into the trap. A second rack was constructed across the regulating outlet channel to prevent adults from migrating up that channel. In 1965 and 1966, few fish were collected at the permanent trap in the tailrace and many adult migrants congregated below the regulating outlet rack. Therefore, a temporary trap was constructed in the regulating outlet channel. Fish in the traps were counted as they were moved into a hopper, which was loaded onto a flatbed truck and hauled to the release site above the reservoir (Ingram and Korn 1969).

The downstream bypass system consisted of intake portals (fish horns), built into the side of the intake tower (Figure 146). These 5 portals were each 20-feet-high and 9-feet-wide and vertically spaced 39.5

feet apart (Ingram and Korn 1969). They allowed juvenile migrants to enter horizontal pipes in the tower which connected to a vertical well where they would have to move over 200 feet vertically (at full reservoir pool) down to the regulating outlet conduit. The portal narrows to a 3-foot-diameter pipe which eventually transitions into the 5-foot-diameter vertical well, which dropped to the regulating outlet at the bottom of the intake tower. Flow into each portal was controlled by a butterfly valve, just beyond the throat of the portal, which was operated fully opened or fully closed. A gate valve, downstream from the butterfly valve, was for emergency use. When the maximum allowable head of 50 feet was on a portal, a flow of 350 cfs occurred (Ingram and Korn 1969).

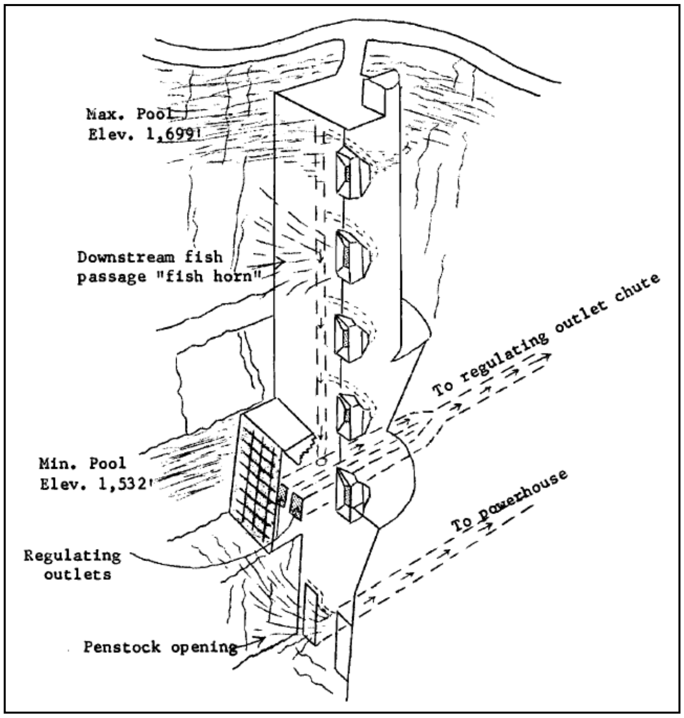

Figure 146: Original intake structure with downstream fish passage "horns" (Ingram and Korn 1969)

Ingram and Korn (1969) evaluated upstream and downstream fish passage at Cougar Dam. They found that fewer adult Chinook salmon returned after the project was completed in 1964. In 1962, 2,121 adult Chinook were passed upstream, with most of them passing in June (Table 6). In 1965, only 68 were passed, mainly in August and September. In addition, numbers of returning fish at Willamette Falls (river mile 26.5 on the Willamette River) in 1965 and later were similar to previous years, further indicating that returns at Cougar were low (Table 7). Of the returning fish from 1965 to 1967, most preferred to enter the regulating outfall temporary trap (Table 8) (Ingram and Korn 1969).

The decrease in returning fish was attributed to a decrease in water quality downstream of the dam. The water temperature in the tailrace channel was too cold for upstream migrants. June and July water temperatures in the tailrace channel were 40 – 45 degrees Fahrenheit, about 10 degrees colder than before the dam was built. Upstream migrants were instead attracted to the warmer water, 50 – 55 de-

Table 6: Counts of adult Chinook salmon passed upstream at Cougar Dam, 1960 – 1967 (Ingram and Korn 1969)

	Year															
	1960		1961		1962		1963		1964		1965 1/		1966 2/		1967 3/	
Month	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
June	258	41.0	776	72.2	1,563	73.7	1,084	52.9	18	2.4	0	0.0	1	0.4	278	59.3
July	285	45.3	116	10.8	199	9.4	530	25.8	476	64.7	0	0.0	20	7.3	0	0.0
August	56	8.9	22	2.0	102	4.8	90	4.4	158	21.5	21	30.9	96	35.3	42	9.0
Sept.	30	4.8	155	14.4	242	11.4	320	15.6	76	10.3	47	69.1	134	49.3	146	31.1
Oct.	0	0.0	6	0.6	15	0.7	26	1.3	8	1.1	0	0.0	21	7.7	3	0.6
Total	629	100.0	1,075	100.0	2,121	100.0	2,050	100.0	736	100.0	68	100.0	272	100.0	469	100.0

1/ Temporary trap operated August 22-September 22, 1965.

2/ Temporary trap operated July 1-October 17, 1966.

3/ Temporary trap operated June 5-28, 1967.

grees Fahrenheit, of the regulating outlet channel, and entered the temporary trap in preference to the permanent tailrace trap. Collection appeared to be better when the temporary trap was operated alone and the water was not discharged through the power plant. However, the effectiveness of the temporary trap was not assessed because the trap did not operate throughout the entire migration season in any year and discharge of cold water from the power plant could not be controlled (Ingram and Korn 1969).

Table 7: Total and expected counts of adult Chinook salmon at Cougar Dam, 1960 – 1967 (Ingram and Korn 1969)

Year	Count at Willamette Falls	Count at Cougar Dam	Expected count at Cougar Dam 1/	Per cent of expected count
1960	14,400	629	-	-
1961	18,900	1,075	-	-
1962	26,100	2,121	-	-
1963	30,500	2,050	-	-
1964	36,300	736	629-?	117-?
1965	29,100	68	629-1,075	6.3-10.8
1966	28,200	272	1,075-2,121	12.8-25.3
1967	55,900	469	2,050-2,121	22.1-22.8

1/ Based on one adult returning per parent counted at Cougar Dam on a 4- and 5-year cycle.

Table 8: Operation of traps and counts of adult Chinook salmon collected at Cougar Dam, 1965 – 1967 (Ingram and Korn 1969)

		1965		1966		1967	
		Perm. trap	Temp. trap	Perm. trap	Temp. trap	Perm. trap	Temp. trap
June	Days operated	22	0	23	0	10	24
	Fish caught	0	0	1	0	0	278
July	Days operated	16	0	19	31	31	0
	Fish caught	0	0	0	20	0	0
August	Days operated	17	10	18	31	31	0
	Fish caught	6	15	0	99	42	0
September	Days operated	24	19	30	30	30	0
	Fish caught	11	36	1	133	146	0
October	Days operated	20	0	17	17	13	0
	Fish caught	0	0	2	16	3	0
	Total days operated	99	29	107	109	115	24
	Total fish caught	17	51	4	268	191	278
	Per cent of season operated	70	20	77	78	85	18
	Per cent of migrants caught	25	75	2	98	42	58

For downstream passage, Ingram and Korn's (1969) evaluation showed that many juvenile migrants did not successfully pass downstream because the collection efficiency was low and many of those collected were killed in the bypass facility. They released groups of marked hatchery yearling Chinook into Cougar Reservoir in the spring of 1965 and 1966 to test passage through the reservoir and collection efficiency at the intake structure. In 1965, a group of 10,058 marked fish were released just above the reservoir. In 1966, 10,000 marked yearling Chinook were released into the same area and two groups of 2,500 were released into the forebay near the intake structure.

An evaluator for capturing downstream migrants was constructed and deployed in the regulating outlet channel. The screened area of the evaluator was 12 feet by 20 feet. A stoplog weir was constructed to shunt regulating channel flows of less than 500 cfs into the evaluator. When flows were greater, the excess flow spilled over the weir. The evaluator began operations in late October 1964 (Ingram and Korn 1969).

Numerous problems were encountered with the evaluator. During the first year of study, it was often out of operation due to mechanical malfunctions and to being flooded out when flows varied in the regulating outlet. In addition, it was unable to collect fish when large flows were released through the regulating outlet. Consequently, data on numbers and timing of fish emigrating from the reservoir were incomplete. During the study, large numbers of exhausted, injured, and dead juvenile Chinook salmon were found in the evaluator. Testing indicated these injuries and mortalities were caused largely by the downstream bypass system, but the situation was aggravated by poor conditions in the evaluator. Because of this, the original evaluator was replaced by an improved evaluator, with the same general dimensions, in the fall of 1966 (Ingram and Korn 1969).

The results of the evaluation showed that collection efficiency was poor for the bypass system (Table 9). Ingram and Korn (1969) thought that the similar passage rates for fish released into the river above the reservoir and into the forebay near the intake structure in 1966 indicated that Chinook moved through the reservoir but were not collected in adequate numbers. They also believed that one of the main reasons for poor passage at the dam was that while Chinook juveniles were found mostly in the upper 15 feet of the reservoir, during the spring migration, the fish bypass portal that was operating was generally 10 to 45 feet deep.

Table 9: Summary of tests to determine success of passage and collection of downstream migrants at Cougar Dam, 1965 - 1966 (Ingram and Korn 1969)

		Mark			
		Anal	R.Pect.	L.Max.	R.Max.
Brood year		1963	1964	1964	1964
Number released		10,058	10,000	2,500	2,500
Date released		4/14/65	3/23/66	3/31/66	4/6/66
Area released		So.Fk.McKenzie just above reservoir	So.Fk.McKenzie just above reservoir	Forebay near horns	Forebay near horns
Purpose of release		Determine success of passage through reservoir and collection in facilities	Determine success of passage through reservoir and collection in facilities	Determine success of collection of fish in vicinity of horn with low head and low attraction flow at release	Determine success of collection of fish in vicinity of horn with low head and low attraction flow at release
Estimated passage efficiency 1/ — To June 30 of release year	Estimated live	2,348	897	263	200
	Actual dead count	410	292	52	59
	Est.live + actual dead	2,758	1,189	315	259
	% live + dead/release	27.4	11.9	12.6	10.4
After June 30 of release year	Estimated live	63	734	207	223
	Actual dead count	15	185	41	43
	Est.live + actual dead	78	919	248	266
	% live + dead/release	0.8	9.2	9.9	10.6
Total passage	Estimated live	2,411	1,631	470	423
	Actual dead count	425	477	93	102
	Est. live + actual dead	2,876	2,108	563	525
	% live + dead/release	28.2	21.1	22.5	21.0

1/ Dead fish listed are actual numbers counted. Live fish are estimates. Passage efficiency is the estimated live plus actual dead fish as a percentage of the total release.

As for survival through the bypass system, it appeared to be very low. Marked hatchery fish were released at several points in the collection and bypass system to determine survival of juveniles during passage. Tests were conducted with the upper two portals in operation and with three different levels of water in the vertical well when each portal was operated. Fish passing through the system survived best when the upper portal operated with a full well. Tests conducted using the second portal showed that survival was low for all fish moving from the portal into the well. It was believed that hatchery test fish survived better than wild fish. Dead fish constituted 40% of the total number of wild fish collected at the evaluator in 1965, 30% in 1966, and 28% in 1967. Tests on and later observations of live wild Chinook collected at the evaluator suggested that many fish were seriously injured, and that extensive delayed mortalities occurred. Hundreds of dead wild Chinook were found during SCUBA dives in the regulating outlet channel in June well after the peak of juvenile emigration. It was believed that many dead fish present in the channel were not recovered since they tended to become lodged under large rocks. In summary, the results of tests and observations to determine survival and condition of juvenile migrants showed large numbers of fish died and many were injured in the bypass system (Ingram and Korn 1969).

Ingram and Korn (1969) recommended that fish passage at Cougar Dam be discontinued. However, they would not preclude starting fish passage back up again if a feasible and successful method could be demonstrated in the future. They also suggested that immediate steps be taken to artificially propagate, in a hatchery, the run of spring Chinook salmon that would have historically spawned upstream of Cougar Dam. In addition, they noted that since the water quality in the tailrace was not acceptable for Chinook salmon, it was possible that fish destined to spawn in the South Fork below the dam would also be affected. Therefore, they thought that Chinook spawning below the dam should be observed for four years and if spawning was unsuccessful, mitigation should also be provided for this portion of the run. The downstream fish passage facilities were eventually abandoned, adult salmon passage was discontinued, and salmon destined for the upper river were artificially propagated as mitigation (Taylor 2000).

To mitigate impacts to salmon and steelhead caused by the Willamette dams, the USACE built two hatcheries, both on the mainstem McKenzie River near Leaburg. The McKenzie Hatchery, first constructed in 1938 and rebuilt in 1975, is used for spring-run Chinook salmon and the Leaburg Hatchery, built in 1953, for steelhead and cutthroat trout.

In 1993, Oregon Department of Fish and Wildlife (ODFW) began placing excess adult Chinook salmon from the hatcheries above Cougar Dam to restore some of the biological contributions salmon historically made to the ecology of the South Fork McKenzie River. These contributions included increased nutrient input and an added food source for predators, including bull trout. Additionally, the progeny of these salmon provided a landlocked Chinook fishery in the reservoir. ODFW assumed that most of the juveniles moving back downstream would be killed passing through the turbines or regulating outlet (Taylor 2000).

In 1998 ODFW began to monitor downstream passage to determine the numbers, sizes, ages, and mortality rates. They completed two years of monitoring of turbine passage and one year of monitoring regulating outlet passage. Two rotary screw traps, one each in the power plant tailrace and the regulating outlet channel were used. Both live and dead fish were captured, counted, measured, and released. The mortality rate for spring-run Chinook passing through the turbines was 7.1% in 1998-1999 and 18.1% in 1999-2000. For rainbow trout passing the turbines the rates were 30.1% and 44.9% in the same years. Regulating outlet mortality rates were 32.3% for spring-run Chinook and 40.0% for rainbow trout in 1998-1999. They did not know why the mortality rates were higher for fish passing the regulating outlet, but that they did see an increase in mortality in both passage methods with an increase in fish size (Taylor 2000).

In 2011, Pacific Northwest National Laboratory released a report detailing fish passage conditions through the regulating outlet and turbines. For the 2009-2010 study they used Sensor Fish, which are constructed of clear polycarbonate plastic, 24.5 mm in diameter by 90 mm long. They weigh 43 grams and are nearly neutrally buoyant in fresh water. Sensor Fish measure the three components of linear acceleration, the three components of angular velocity, temperature, and absolute pressure at a frequency of 2000 Hz per sensor channel over a recording time of about 4 minutes. The Sensor Fish are used to collect hydraulic data and interactions with structural components as they pass the dam via the turbine route or the regulating outlet route (Duncan 2011).

For the regulating outlet, two test conditions were evaluated, 440 cfs and 1040 cfs. Results showed that more than 97% of the 35 Sensor Fish released had at least one significant collision event and almost 86% had multiple collision events. The vast majority of these collision occurred on the outlet chute. For turbine passage, three operational conditions were tested at turbine unit 2: the minimum wicket gate opening of 13.6 degrees which corresponds to 340 cfs, the maximum wicket gate opening of 24.5 degrees and 550 cfs, and the peak efficiency wicket gate setting of 19.1 degrees and 455 cfs. All of the 34 Sensor Fish released experienced at least one significant strike, collision, or shear event during passage through the turbine and more than 92% experienced multiple events. No collision events occurred in the penstock (Duncan 2011).

At the same time that Pacific Northwest National Laboratory was conducting their study with Sensor Fish, Normandeau Associates was releasing spring-run Chinook salmon. Results showed a 48-hour survival rate of 88% for the regulating outlet route and 39% for the turbine route (Duncan 2011).

As stated earlier, in 2005 the USACE completed the water temperature control (WTC) facility for Cougar Dam, which improved downstream conditions for fish. As part of the project, the original fish bypass intake portals were removed. Since it began operating in January 2005, the facility has substantially shifted the thermal hydrograph for the dam's water releases back to the natural temperature hydrograph of the river immediately downstream of the dam. This improvement has increased salmon survival in the mainstem McKenzie River and the South Fork below the dam. Cougar Dam is the only USACE project in the Willamette River Basin with permanent temperature control capability. In addition, during the time when the reservoir was lowered to construct the WTC structure, the turbines were upgraded with fish friendlier runners that utilize minimum gap technology (USACE et al 2007).

In 2008, the National Marine Fisheries Service (NMFS) released the Willamette Basin Biological Opinion. The Opinion states that "The Willamette Project has adversely affected Upper Willamette River Chinook and Steelhead by blocking access to a large amount of their historic habitat upstream of the dams and contributing to degradation of their remaining downstream habitat". In addition, "The Proposed Action for continued operation and maintenance of the U.S. Army Corps of Engineers' Willamette Valley Project is likely to jeopardize the continued existence of Upper Willamette River Chinook salmon (*Oncorhynchus tshawytscha*) and Upper Willamette River steelhead (*O. mykiss*), which are listed as threatened under the Endangered Species Act (ESA), and to adversely modify or destroy designated critical habitat for these species. NMFS provided the Action Agencies (USACE, Bonneville Power Administration, and the Bureau of Reclamation) with a Reasonable and Prudent Alternative (RPA) to supplement the proposed actions from the 2007 Action Agencies' Supplemental Biological Assessment (USACE 2010). One of the proposed actions in the Supplemental Biological Assessment is the construction of a permanent collection and transport facility at Cougar Dam that would restore connectivity to the watershed above the dam (USACE et al 2007). In the Biological Opinion, NMFS stated that several additional major actions would significantly help the recovery of listed salmon and steelhead in the Willamette Basin. One of these major actions, that NMFS wanted implemented by 2014, was construction and operation of downstream passage facilities to safely pass emigrating listed fish at Cougar Dam. NMFS concluded that the actions proposed by the Action Agencies, combined with additional actions detailed in the RPA would ensure that the operation of the Willamette Project avoids jeopardy, contributes to recovery of ESA salmon and steelhead, and avoids destruction of critical fish habitat.

In 2010, the USACE finished construction on an adult collection, holding, and transfer facility below the dam in the power plant tailrace that will allow biologists to collect adult fish from the river and transport them upstream of the dam during spawning season (described in more detail in the Current Fish Passage section below).

Also in 2010, the USACE released the Cougar Dam Downstream Passage Alternatives Study 60% Alternatives Report. The report states that given recent studies, juvenile salmon are able to migrate through Cougar Reservoir and find currently available passage routes through Cougar Dam via the temperature control tower. Therefore, efforts to improve downstream passage survival will focus on alternatives where collection facilities are at the dam as opposed to facilities at the head of the reservoir. Any downstream passage facility will have to be able to handle the potential 170' reservoir elevation fluctuation.

Consequently, the USACE narrowed down the alternatives from the previous 30% Alternatives Report to six "at the dam" alternatives and then describes each alternative. The six alternatives, taken directly from the 60% Alternatives Report, are:

1. Weir Box/Collection Channel with WTC tower modification for lower pool operation, with holding barge and truck transport.

   The Weir Box Collection System utilizes the existing temperature control weirs and wet well to attract and collect fish. Fish would be attracted into the WTC tower over one or both of the existing temperature control weirs above the regulating outlet(s) and a surface outlet with 100 cfs attraction flow would be used to collect the fish inside the existing wet well. The surface outlet would be plumbed through the existing WTC weir above the penstock, with attraction flow passing back out of the WTC tower over the penstock-side weir to the Weir Box Collection System floating in the forebay.

   The Weir Box Collection System would be a floating structure containing dewatering screens, attraction flow pumps, and bypass flume, and would be moored on a rail system on the upstream of the temperature control tower to track forebay elevation. After fish and attraction flow pass over the penstock-side weir gate, the flow would pass through dewatering screens and the bypass flow and fish would be sent to a separation and holding barge, where they would be lifted to the top of the tower for truck transport.

2. Weir Box/Collection Channel with WTC tower modification for lower pool operation, with tower bypass.

   The concept for this alternative is the same as the previous alternative, but with a tower bypass pipe for fish transport rather than truck transport. After the fish have been collected into the Weir Box Collection Channel and passed the dewatering screens, a collection pipe with a flexible hose connection will transport the fish to a bypass pipe routed through a new tunnel in the left abutment, and downstream to a release site. The bypass pipe will have "ports" spaced at 25-foot intervals over the operating range, where connections can be automatically adjusted as the pool fluctuates.

3. Floating Screen Structure on upstream side of WTC tower with tower modification for lower pool operation, with holding barge and truck transport.

   This alternative involves installing a guide or track to the existing WTC tower that allows a Floating Screen Structure (FSS) to float up and down along the upstream face of the WTC tower as the reservoir elevation changes. The FSS concept uses up to 1,000 cfs of project outflow as attraction flow. Up to 1,000 cfs of Project outflow would be drawn as surface flow through the FSS entrance, dewatered through v-screens, and passed over the penstock-side WTC weir gate into the WTC tower and out the regulating outlet or penstock. Fish collected in the FSS and a small percentage of the flow would bypass the screens through a bypass channel at the downstream end of the screens. The bypass flow and fish would be sent to a separation and holding barge, where they would be lifted to the top of the tower for truck transport.

4. Floating Screen Structure on upstream side of WTC tower with tower modification for lower pool operation, with tower bypass.

   The concept for this alternative is the same as the previous alternative, but with a tower bypass pipe for fish transport rather than truck transport. After the fish have been collected into the FSS and passed the dewatering screens, a collection pipe with a flexible hose connection will transport the fish to a bypass pipe routed through a new tunnel in the left abutment, and downstream to a release site. The bypass pipe will have "ports" spaced at 25-foot intervals over the operating range, where connections can be automatically adjusted as the pool fluctuates.

5. Floating Surface Collector in intake tower cul-de-sac with tower bypass.

   The Floating Surface Collector (FSC) structure will generally consist of a floating barge structure with a pumped attraction flow, dewatering v-screens, and pumped return flow to the reservoir. The FSC would be similar in concept to the facilities in operation at Upper Baker Dam and in design for Swift Reservoir, except that the Cougar FSC barge would only contain the screens and pumps. Fish transport would be provided near the WTC tower. The FSC structure would be constructed from portable barges latched together to contain dewatering screens, a collection channel, and attraction flow.

   The FSC as described in this alternative includes guidance nets extending from the upstream end of the FSC to the shoreline. An adaptive management approach to the guide nets is proposed as described in the Guidance/Exclusion Features section [Not available in this report].

   After the fish have been collected into the FSC and passed the dewatering screens, a collection pipe with a flexible hose connection will transport the fish to a bypass pipe routed through a new tunnel in the left abutment, and downstream to a release site. The bypass pipe will have "ports" spaced at 25- foot intervals over the operating range, where connections can be automatically adjusted as the pool fluctuates.

6. Floating Surface Collector in intake tower cul-de-sac with holding barge and truck transport.

   The concept for this alternative is the same as the previous alternative, but with truck transport for fish transport rather than a bypass. After the fish have been collected into the FSC and passed the dewatering screens, they will be sent through a transport pipe to a separation and holding barge, where they would be lifted to the top of the tower for truck transport.

Table 10 gives the cost estimate for the six alternatives.

Table 10: Downstream passage alternatives cost estimates (USACE 2010)

Alternative	Construction ($)	Lands and Damages Cost ($)	Planning, Engineering, and Design Cost ($)	Construction Management Cost ($)	Total Capital Project Cost ($)	Total Annual O&M Cost ($)	Present Value of Total Annual O&M Cost ($)	Total Life Cycle Project Cost: 50 Years ($)
FSC - 220 CFS, with nets, truck transport	$ 71,394,954.73	$ -	$ 13,121,137.92	$ 8,211,816.04	$ 92,727,908.69	$ 1,469,178.98	$ 29,634,187.54	$ 122,362,096.23
FSC - 220 CFS, with nets, bypass pipe	$ 81,458,327.32	$ -	$ 14,963,397.92	$ 9,367,707.64	$ 105,789,432.88	$ 1,481,853.98	$ 29,889,849.60	$ 135,679,282.48
Weir Box, truck transport	$ 48,765,935.27	$ -	$ 8,964,434.22	$ 5,609,502.92	$ 63,339,872.41	$ 942,095.15	$ 19,002,602.69	$ 82,342,475.10
Weir Box, bypass pipe	$ 58,875,932.72	$ -	$ 10,815,149.76	$ 6,770,732.26	$ 76,461,814.74	$ 759,770.15	$ 15,325,002.27	$ 91,786,817.00
Floating Screen, truck transport	$ 72,705,661.90	$ -	$ 13,362,125.16	$ 8,362,595.60	$ 94,430,382.66	$ 985,542.54	$ 19,878,961.50	$ 114,309,344.15
Floating Screen, bypass pipe	$ 82,783,781.47	$ -	$ 15,206,875.76	$ 9,520,134.87	$ 107,510,792.10	$ 985,542.54	$ 16,201,361.07	$ 123,712,153.18

Notes:
All costs are order-of-magnitude costs for comparative purposes only.
Construction cost includes escalation to the mid-point of construction and contingency.

To verify the previous studies, in 2011 the USGS studied the movements and passage of juvenile spring-run Chinook salmon at Cougar Reservoir and Dam. A total of 26 wild salmon and 411 hatchery salmon were tagged and released at the head of the reservoir between March 7 and May 21, 2011. Autonomous hydrophones placed across the reservoir at six locations were used to determine general fish movement. In addition, acoustic signals from tagged salmon near the temperature control tower were detected using three 4-hydrophone systems. Dam passage was determined using presence data from these hydrophones. A dam passage determination was made if the first detection of the last transmitter message was at any of the four hydrophones closest to the water surface (Beeman et al 2012).

Results of the study showed that movements within the reservoir were directional, with fish commonly migrating repeatedly from the head of the reservoir downstream to the dam outlet and back. Travel times for the first trip from the release point to the temperature control tower were similar for hatchery and wild fish. Times ranged from 0.6 to 76.6 days for hatchery fish and 3.3 to 36.4 days for wild fish, with median values of 9.7 and 9.1 days for hatchery and wild fish, respectively. A total of 342 hatchery fish and 18 wild fish were detected near the temperature control tower. The travel times from release point to dam passage were similar for hatchery and wild fish. The range for the hatchery fish was 2.5 to 94.6 days, with a median time of 34.5 days. For the wild fish, the range was 17.2 to 110.2 days, with a median time of 34.2 days. A total of 49 hatchery fish and 6 wild fish passed the dam, with most passage occurring at night (Beeman et al 2012).

Current Fish Passage at Cougar Dam

A collection, holding, and transfer facility was completed in 2010 to allow adults migrants to be hauled upstream of the dam and complete their spawning migration. Downstream migration is mainly through the regulating outlet or powerhouse. The USACE is in the process of deciding on a preferred alternative for improving downstream passage.

Upstream Passage

In 2010, a $10.4 million dollar adult collection facility was completed in the powerhouse tailrace channel on the right bank of the South Fork McKenzie River (Figures 147 and 148). The facility was constructed to allow for collection, sorting, holding, and transporting adult migrating fish. A Half-Ice Harbor fish fishway was constructed to get the upstream migrants to the collection area (Figures 149 and 150). The entrance to the fishway is just downstream of the powerhouse outfall to help fish easily find it. The fishway flow is 30 cfs and 100 cfs of auxiliary water is adder at the downstream end to better attract fish to the entrance. At the top of the fishway, fish jump over a finger weir into the pre-sort pool (Figure 151). A crowder is used to concentrate fish at the upstream end of the pre-sort pool and then they are attracted to a false weir which they jump over and slide down a flume to an anesthetic tank or to a post-sort pool (Figures 152 and 153). The post-sort pools (Figure 154) sit directly over the truck loading area (Figure 155). The pools are emptied through a 3-foot-diameter port in the bottom which is attached to the truck by movable bellows (Figure 156). The loaded fish are transported approximately 9 miles and released at a location about a mile upstream of the head of the reservoir (Figure 157). The USACE are using a new truck based on the design of the Tacoma Power trucks used in the Cowlitz River system (Greg Taylor, Personal Communication, Nov 7, 2011).

Construction of the facility did not require lowering of the reservoir, but the power plant tailrace channel was dewatered and all water was routed through the regulating outlet (Corpspondent Nov Dec 2010). The facility is working well with some fairly minor modifications needed to make it operate better. The facility is operated solely for collection and transport, and therefore they have to be gentler with the fish than at a hatchery facility. From its inception through October 2011, the facility has collected about 400 spring-run Chinook salmon and hundreds of resident fish species (Greg Taylor, Personal Communication, Nov 7, 2011). The spring-run Chinook average about 15 pounds, but can be greater than 30 pounds. Operation and maintenance for the facility is approximately $60,000 - $100,000 per year (Greg Taylor, Personal Communication, May 25, 2012).

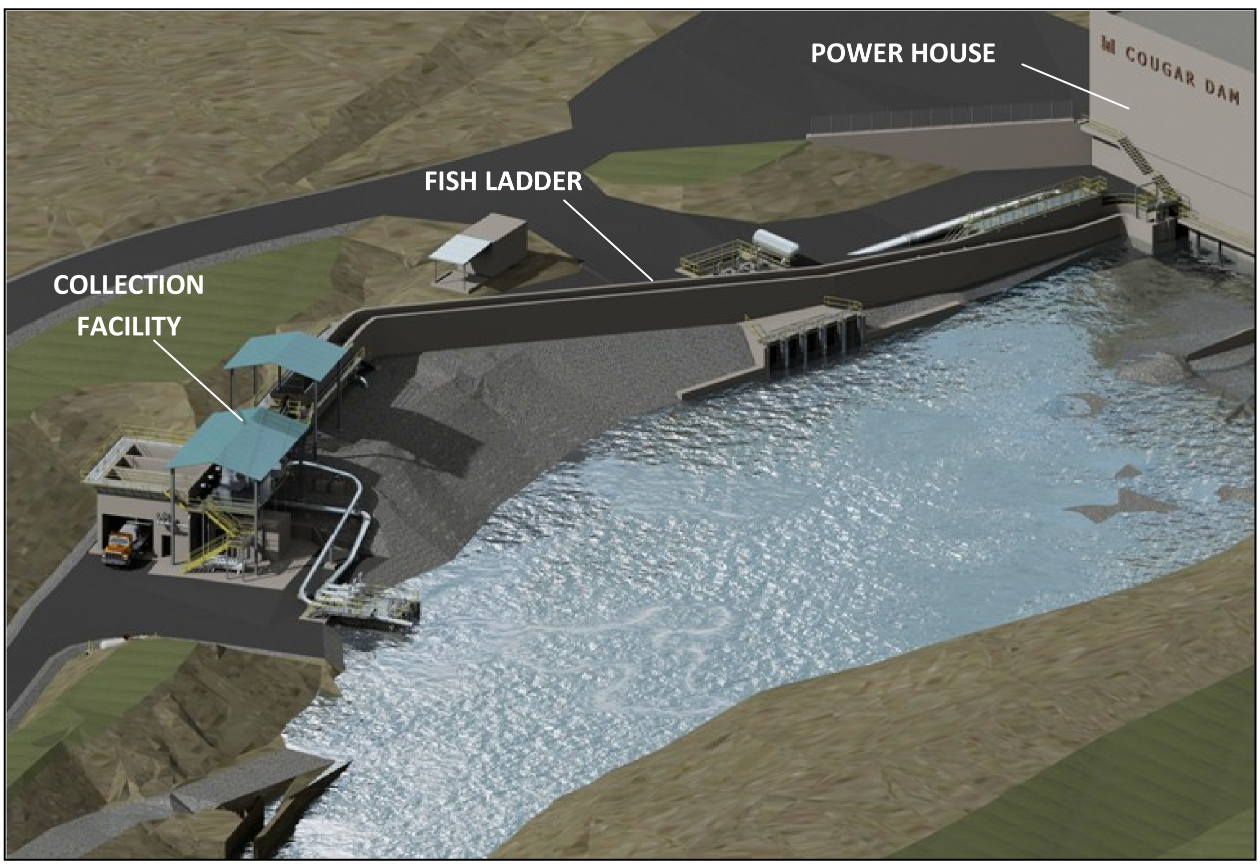

Figure 147: USACE Adult Fish Collection Facility (Courtesy of USACE)

Figure 148: Overview of the Adult Collection Facility (Courtesy of USGS)

Figure 149: Looking Down Half Ice Harbor Fishway (CA Dept. of Water Resources)

Figure 150: Half Ice Harbor Fishway - Photo from Fishway Entrance (CA Dept. of Water Resources)

Figure 151: Finger Weir and Pre-Sort Pool at Top End of Fishway (CA Dept. of Water Resources)

Figure 152: False Weir and Flume to Sorting Area (CA Dept. of Water Resources)

Figure 153: Sorting Area and Post-Sort Pools (CA Dept. of Water Resources)

Figure 154: Post-Sort Pool and Fish Loading Port (CA Dept. of Water Resources)

Figure 155: Truck Loading Area (CA Dept. of Water Resources)

Figure 156: Truck Loading (Courtesy of USACE)

Figure 157: Fish Release into Upper South Fork McKenzie River (Courtesy of USACE)

Downstream Passage

There are currently no downstream passage facilities at Cougar Dam. Downstream migrants must pass the dam by entering the temperature control facility and then pass through the penstock and turbines or the regulating outlet.

As of November 2011, the USACE have not decided on a preferred alternative for downstream passage. All six alternatives from the 2010 alternatives study are still being considered (Greg Taylor Nov 7 2011) and the USACE hopes to have a decision made by fall 2012.

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North Fork Hydroelectric Project

Location: On the Clackamas River, Oregon, 25 miles southeast of Portland, with the lowest dam about 23 river miles from the confluence with the Willamette River

Owners: Portland General Electric Company

Dam Name: River Mill	**Hydraulic Height:** 82’	**Year Constructed:** 1911
Dam Name: Faraday	**Hydraulic Height:** 56’	**Year Constructed:** 1965
Dam Name: North Fork	**Hydraulic Height:** 145’	**Year Constructed:** 1958

Target Species: Spring-run Chinook salmon, fall-run Chinook salmon, coho salmon, steelhead trout, coastal cutthroat trout, and Pacific lamprey

Upstream Passage: Half Ice Harbor fishway at River Mill Dam. Pool and weir fishway from below Faraday Dam to above North Fork Dam.

Downstream Passage: Fish pass all three dams via a 20-inch-diameter, 7-mile-long downstream migrant bypass pipeline.

Project Description

The North Fork Hydroelectric Project (Figure 158) is part of the Clackamas River Hydroelectric Project, and consists of three dams, River Mill, Faraday, and North Fork, which are owned and operated by Portland General Electric.

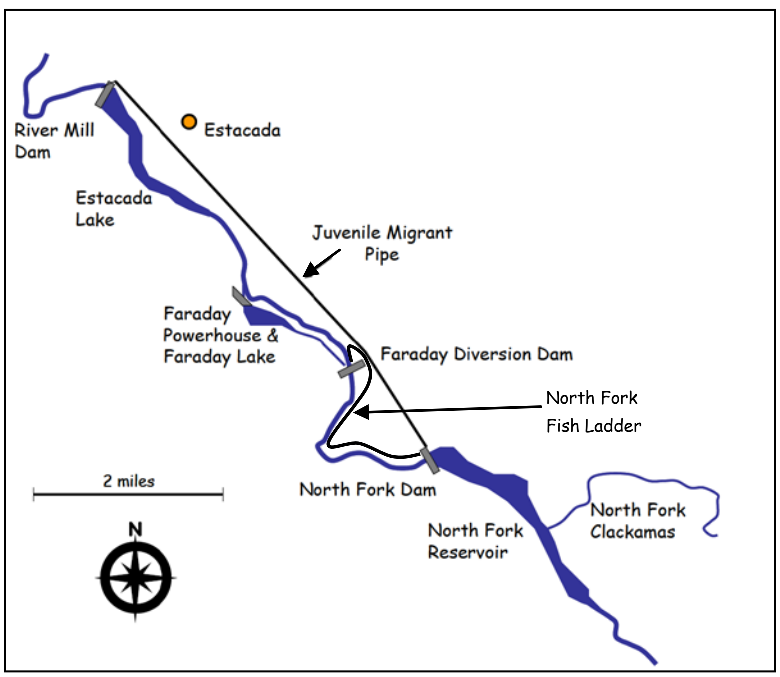

Figure 158: North Fork Hydrolectric Project

The initial 50-year North Fork Project license, for only North Fork Dam, was issued by the Federal Power Commission (predecessor to the Federal Energy Regulatory Commission) on January 18, 1957. The license was amended in 1965 to include the Faraday and River Mill developments. The Faraday and River Mill developments were both built prior to the establishment of the Federal Power Act and were therefore not licensed prior to being included in the North Fork Project federal license (PGE 2004). The license expired on August 31, 2006 and PGE operated under annual licenses until a new 40-year license was issued on December 21, 2010 (FERC 2010).

River Mill Dam, completed in 1911, is approximately 23 river miles from the Clackamas River's confluence with the Willamette River, and is the most downstream dam in the project (Figure 159). The 85-foot-tall (82-foot hydraulic height), 936-foot-long concrete dam creates 2,300-acre-foot Lake Estacada, which impounds about 2.8 miles of the Clackamas River. Five 11-foot-diameter steel plate penstocks route water to five Francis turbines in the powerhouse with a total capacity of 25 MW (PGE 2004).

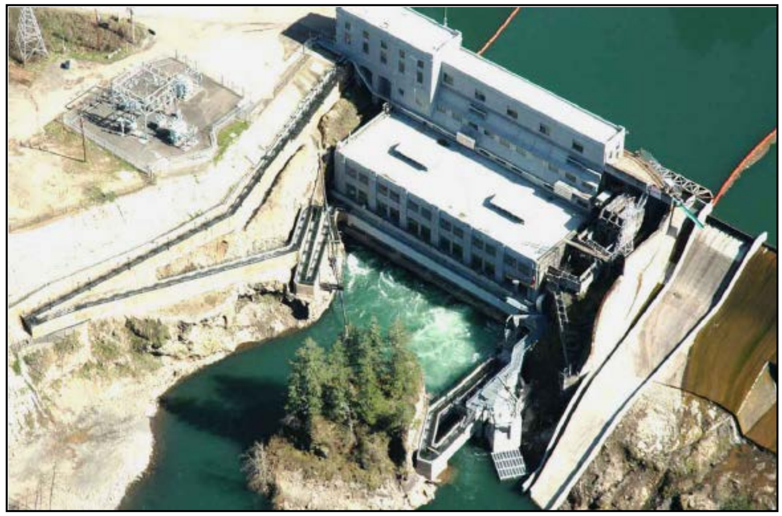

Figure 159: River Mill Dam (Courtesy of PGE)

Faraday Division Dam, the middle dam for the Project, is 84 feet high (56-foot hydraulic height) and 407 feet long (Figure 160). It was completed in 1965 and backs up the Clackamas River for 1.6 miles in 1,200-acre-foot Diversion Dam Reservoir. The spillway for the dam is 255 feet long, consisting of two sections topped by 125-foot-long, 10-foot-high steel drum gates. The dam does not have any power generating facilities but is used to divert water into a 23-foot-diameter, 5-mile-long tunnel which flows into a canal, then into Faraday Lake. Faraday Lake is small, with only 430 acre-feet of volume, and is backed up behind Faraday Lake Dam. The lake is also the forebay for the Faraday Powerhouse, which is capable of generating as much as 46 MW of power using 6 Francis turbines. The Faraday Dam also has an emergency spillway containing five gated outlets (PGE 2004).

Figure 160: Faraday Dam (CA Dept. of Water Resources)

North Fork Dam was completed in 1958 and is the most upstream development of the Project (Figure 161). It is a 207-foot-high (145-foot hydraulic height), 676-foot-long concrete arch dam which creates the 21,000-acre-foot North Fork Reservoir. North Fork Reservoir impounds approximately 4.6 miles of the Clackamas River. Two 14-foot-diameter penstocks route water to two Francis turbines in the North Fork powerhouse, which have the capability to generate approximately 58 MW. Three 50-foot-wide by 37.5-foot-tall tainter gates regulate flow into a 200-foot-long ogee type spillway which discharges into a 250-foot-long chute. Maximum capacity of the spillway is approximately 150,000 cfs (PGE 2004, PGE 2006).

Figure 161: North Fork Dam (CA Dept. of Water Resources)

Fish Passage History

The following is all directly from Barbara Taylor's Salmon and Steelhead Runs and Related Events of the Clackamas River Basin – A Historical Perspective (1999).

> In the early and middle 1800s, the Clackamas River was recognized for its salmon and steelhead runs. Livingston Stone, employed by the U.S. Fish Commission to explore potential hatchery sites throughout the Columbia River Basin, professed in 1877 that "*probably no tributary of the Columbia has abounded so profusely with salmon in past years as this river (the Clackamas)*" (US Commission of Fish and Fisheries 1877).
>
> The runs began declining in the mid-1800s, primarily due to overharvest in the Columbia River and on the lower Clackamas. By the late 1870s the spring chinook run to the Columbia River had already dropped below historic levels. This drop led cannery personnel in the Pacific Northwest to start experimenting with fish culture as a means to improve the runs. The first hatchery in the Columbia River Basin (also the second in the United States) began operating on the Clackamas River in 1877.
>
> In 1902, the Oregon Water Power and Railway Company, a predecessor of Portland General Electric, started work on Cazadero Dam in the Clackamas River about 1.25 miles upstream from the town of Estacada. Workers completed the timber-crib, rock-filled dam in 1907. A wooden fish ladder was included as part of the dam's original construction.
>
> When the dam was completed, fish propagators began operating an egg-taking station just below it. These activities prevented full use of the ladder. The fish ladder also suffered repeated damage by floodwaters in the early years and was repaired frequently. Records show the ladder being repaired following a flood the winter of

1909-1910. The ladder was damaged badly by floods in 1917 and was not repaired because egg-taking activities downstream at River Mill Dam prevented fish from reaching Cazadero. In 1939, the company rebuilt the ladder at a cost of about $22,000.

During the 1950s, the company modified the project to handle the water discharged by two units operating on peaking loads at North Fork. A new intake was constructed above the original Cazadero Dam, and a ½-mile-long concrete-lined tunnel was built. The company also built a new turbine generator beside the original powerhouse. A new fish ladder, constructed as part of the North Fork Project, provided passage around both the Cazadero and North Fork dams. The projects were completed in 1958.

In December 1964, a major flood on the Clackamas River severely damaged Cazadero Dam. The dam ``collapsed when another flood hit five weeks later in January 1965. It was replaced with a new concrete dam, named Faraday, in 1966.

The Oregon Water Power and Railway Company began building a second plant on the Clackamas River in 1909. The River Mill project, below the Cazadero plant and less than one mile northeast of Estacada, started generating power in 1911.

Upon completion, River Mill contained a concrete fish ladder that had received approval from Oregon's Master Fish Warden. The ladder was considered a model design for its day. Fish propagators immediately placed a fish rack below the ladder entrance to collect brood stock. The rack prevented full use of the fish ladder for migration over the dam until 1940. Eggs were taken below the ladder from 1913 through 1939, when the hatchery was abandoned.

Figure 162: Old River Mill Fish Ladder - 1968 (NOAA Fisheries)

In 1926, Portland General Electric improved the ladder at River Mill, although salmon migration was stopped most of the time by egg-taking operations. They constructed additional pools at the lower end of the ladder, widened turning and resting pools, and moved apertures between the pools to meet new state requirements. The ladder was improved again in late 1939 (Figure 162). This time the company improved the fish ladder entrance and installed an attraction water pump and diffusion chamber as recommended by the U.S. Bureau of Fisheries.

Passage improvements made at Cazadero and River Mill dams in 1939 restored fish passage to the upper Clackamas basin. When the new North Fork ladder became operable in 1958, the ladder over Cazadero Dam was removed.

In 1954, nearly half a century after initial investigations, Portland General Electric began new studies for the North Fork hydroelectric development. The company received pre-license consent from the Federal Power Commission for the project in September 1956. This consent came after Portland General Electric and the Oregon Department of Fish and Game reached agreement on the scope of the facilities for handling migratory fish. The project was completed in 1958. Upon completion, the North Fork project included extensive fish passage facilities bypassing both Cazadero (later named Faraday) and North Fork dams. The project's 1.9-mile fish ladder transported fish from the river below Faraday and deposited them above North Fork Dam after climbing 196 feet. The ladder, 10 feet wide and 6 feet deep, included a fish trap that has normally been operated from June to October.

The company also built facilities to help downstream migrants. These included a collection device above North Fork Dam to attract the migrants and convey them to the North Fork fishway. Near the lower end of the fishway, they assembled a "separator" to pass fish from the fishway into a pipeline to carry them to the river below River Mill Dam. Today, downstream migrants are counted at the separator. Downstream migrants can also leave North Fork Reservoir over the spillway during high water. Construction of the North Fork project significantly improved fish passage upstream from River Mill Dam and Estacada Lake. Studies have shown that the North Fork screen and diversion facility effectively attracts and passes salmon and steelhead smolts because they typically migrate downstream near the water surface. The downstream migrant bypass is less effective at attracting chinook smolts away from the turbines as chinook often migrate at greater depths.

After discussions with the State of Oregon regarding fish losses and enhancements, Portland General Electric proposed to pay up to one million dollars for building a fish hatchery to be operated by the State of Oregon. The company and State reached formal agreement in 1975. The company committed to paying up to one million dollars for a fish hatchery capable of producing 50,000 pounds of salmonids annually. The state agreed to pay for any expenses to enlarge the hatchery or to produce more fish. All costs of operating and maintaining the hatchery are to be shared equally by the company and State. In signing the agreement, Portland General Electric did not admit past or present liability for abundance of fish on the Clackamas River, but entered the agreement with the purpose of cooperatively increasing salmon production of the river. In addition, the agreement stipulated that the company was not required to construct additional fish passage facilities, protection devices or modify power operations to improve fish passage. Construction of the hatchery began in 1977 on land that the company deeded to the State. The 17.5-acre site, which now supports the Clackamas Hatchery, lies next to McIver State Park on the Clackamas River.

Current Fish Passage

Current Upstream Passage

At River Mill Dam, a new fishway was completed in 2006 for approximately $16 million dollars. It is a Half Ice Harbor, pool and weir type with orifices (Figure 163) and was designed to incorporate the needs of lamprey as well as salmonids. The fishway has 88 pools (the upper 8 being exit pools and having adjustable weirs) designed to have a one foot drop between pools. Typically, the pools are 6 feet wide by 10 feet long, and average 6.5 feet in depth (6 feet deep at the upstream end of the pool and 7 feet deep at the downstream end). However, the pools on bends are longer, and the upper 16 pools are deeper to accommodate varying forebay water elevations. The weirs in the fishway are 3 feet wide and the typical pool differential is 1 foot (Bartlett and Cramer 2006). The weirs contain orifices which

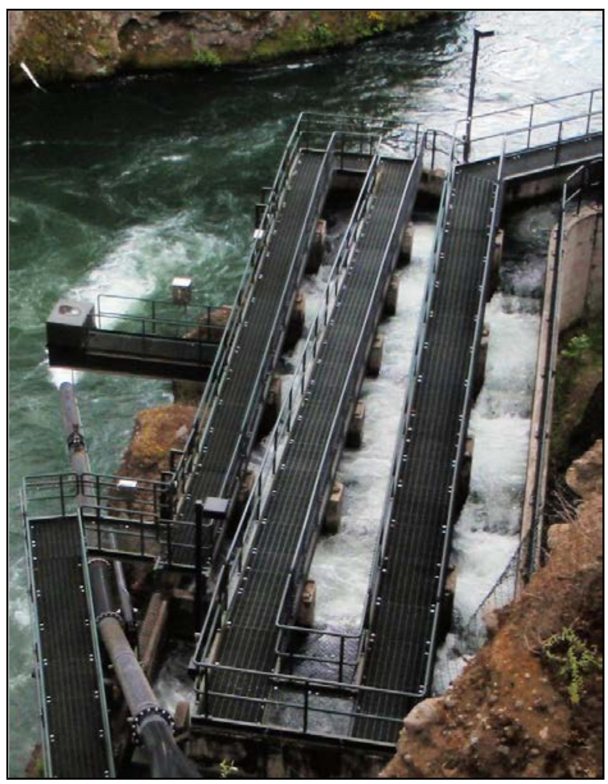

Figure 163: River Mill Half Ice Harbor Fishway (CA Dept. of Water Resources)

are 1.5 feet wide by 1.25 feet high. Flows in the fishway is roughly 19 cfs, with the weirs passing approximately 6.4 cfs at an average velocity of 4.6 fps and the orifices passing approximately 12.9 cfs

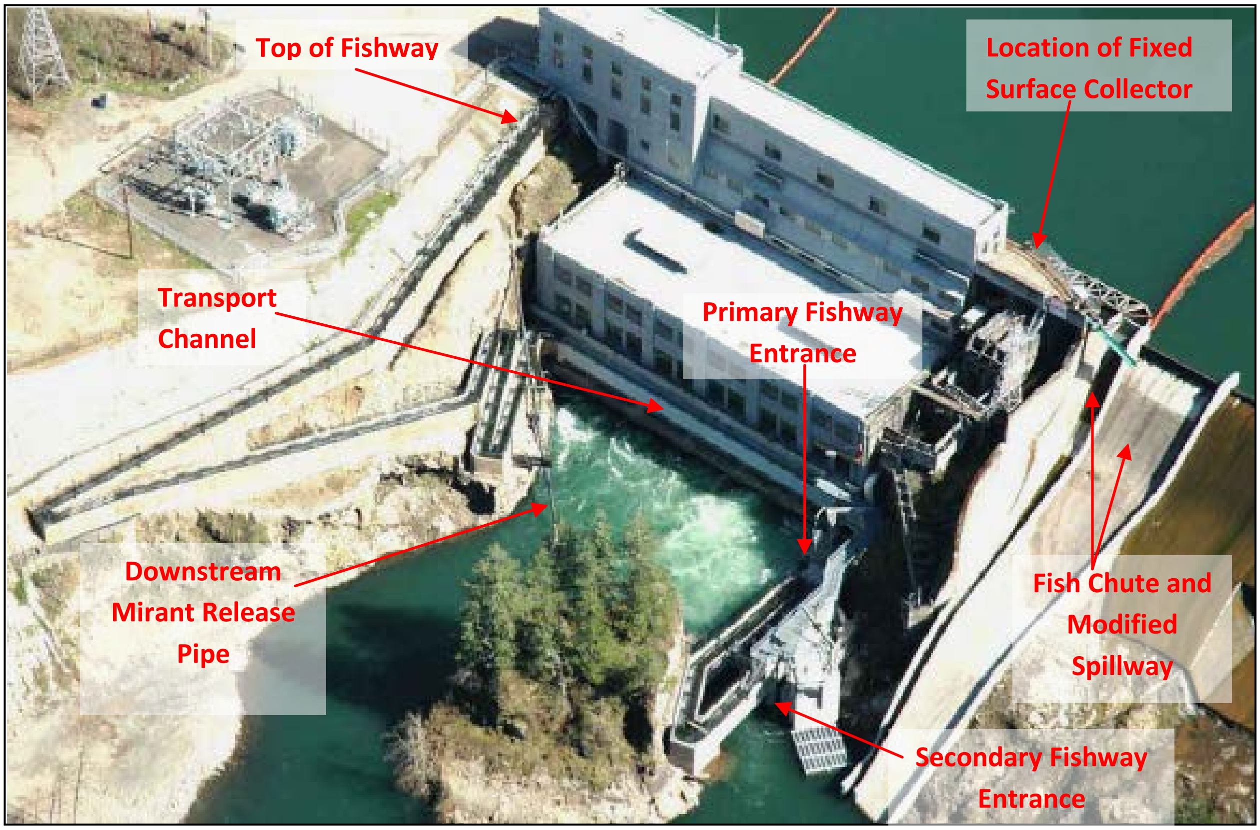

Figure 164: River Mill Dam Fishway Entrances and Routing (Courtesy of PGE)

with an average velocity of 6.9 fps (PGE 2012b). Connecting the lower pools of the ladder in the middle of the channel to the main portion of the ladder on the right bank is a section of transport channel which runs along the downstream face of the powerhouse.

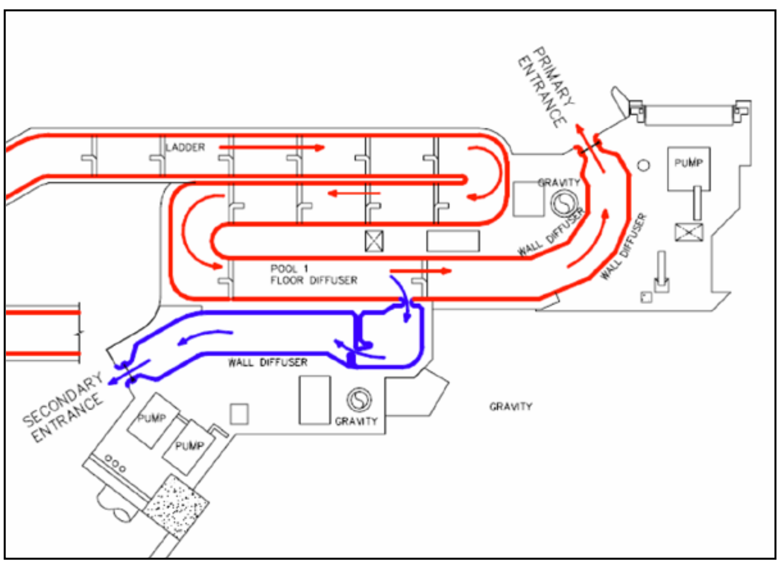

Figure 165: River Mill Fishway Entrances (PGE 2012b)

The fishway has two entrances, a 2.6-foot-wide primary entrance next to the powerhouse discharge and a 2.2-foot-wide secondary entrance next to the spillway (Figures 164 and 165). Each entrance has a gate that sits within a bulkhead slot. At fully open, the top of the gate is flush with the bottom of the ladder. The gate rises as the tailwater elevation ris130es to maintain the requited head at the entrance (PGE 2012b). The fishway flow plus additional attraction flow at the primary entrance maintains a head differential of 12 to 18 inches and varies from 95 cfs to 245 cfs. The secondary fishway entrance is designed to have a 6-inch head differential at 35 cfs during non-spill conditions but increases to 12 to 18 inches and 130 cfs during spill conditions. Flow for the fishway entrances comes from three sources: fishway flow, three pumps, and gravity supply from the forebay. Flow from all three sources is continuously controlled and monitored by a programmable logic control computer (Bartlett and Cramer 2006).

Initial monitoring of the River Mill Fishway showed no unusual concentrations of fish and fish seemed to negotiate the ladder with minimal effort. In addition, post-construction average arrival dates for fish at the North Fork fish trap are consistent with those from the previous 10 years (PGE 2008).

Figure 166: North Fork Fishway - Photo taken from Adult Trapping Facility (CA Dept. of Water Resources)

North Fork Fishway provides passage for upstream migrating fish around Faraday and North Fork dams. The fishway is a concrete pool and weir type, with pools 10 feet wide by 6 feet deep (Figure 166). The fishway has both long and short pools. The short pools have 17” square orifices that alternate sides and the long pools have a central 24-inch-wide by 18-inch-high orifice. The weirs in the fishway are 7 feet wide and the typical pool differential is 1 foot (PGE 2012b). The 1.9-mile-long fishway is proclaimed by PGE to be the longest one in operation in the world (PGE 2011). It rises approximately 200 feet and has a design flow of approximately 45 cfs, with about 10 cfs passing through the orifices and 35 cfs spilling over the weirs (PGE 2012b).

Figure 167: North Fork Fishway Entrance (PGE 2012b)

The entrance of the fishway is a 4-ft wide slot with two leaf gates which allow restriction down to 28 inches for adjustment of head differential (Figure 167). Auxiliary flow of 100 cfs is currently added to the 45 cfs fishway flow for a total of 145 cfs at the entrance. PGE are adding 90 cfs of auxiliary flow in summer 2012 to increase the entrance flow to 235 cfs (Doug

Cramer, Personal Communication, May 24, 2012).

Until 1998, fish could travel unimpeded up the entire length of the fishway to exit above North Fork Dam (PGE 1999). Currently, all fish are trapped approximately 600 feet up the fishway and all wild salmonids are either returned to the fishway to continue upstream or trucked above North Fork Dam. All hatchery returns are recycled downriver or used for fishing opportunities (Bartlett 2006).

PGE will build a new adult sorting facility in 2012, which will be situated at the upper end of the fishway just downstream from North Fork Dam. The facility is designed to provide hands-free counting and sorting capabilities and has significantly more fish holding capacity than the existing trap, along with capabilities to enumerate and trap Pacific lamprey (PGE 2012a).

Current Downstream Passage

At North Fork Dam, downstream migrants enter a bypass system along with 245 cfs and move down a concrete migrant channel on the right bank of the forebay. The downstream migrant channel is a 10 feet wide and 360 feet long. Normally, up to 35 cfs of the migrant channel flow is routed through one of five gates, based on forebay elevation, and into an upper pool of the fishway. Of the remaining water in the migrant channel, approximately 200 cfs is directed into a sump where 190 cfs passes through the two traveling screens. Until 2011, fish and the remaining 10 cfs left the sump through the bypass entrance, down a drop structure, and discharged through a short horizontal pipe into a pool of the fishway (McMillen 2011). The fish traveled about 1.6 miles down the fishway to a separator, which diverted them into a holding tank where they were identified and counted. Fish were then released into a bypass pipe that carried them downstream about 5 miles to the release point in the river below River Mill Dam (PGE 2012a). The bypass pipe diameter varied between 18 and 24 inches, and transitioned between steel, concrete cylinder pipe, transite, and high density polyethelene pipe. The pipeline was either buried or supported by cables on the hillside adjacent to E. Faraday Road (MGH Associates 2011).

In the new configuration, fish and approximately 10 cfs exit the traveling screen sump via a new bypass connection and enter a 2-foot-wide rectangular flume (Figure 168) INSERT DS MIGRANT ENTRANCE FLUME ISOMETRIC DRAWING WITH BLOCK - AS FULL PAGE LANDSCAPE ORIENTATION. The flume contains a debris rack, an isolation gate, and a ramp weir (Figure 169), which controls the flow into the pipeline. After the weir, the flume transitions into the 20-inch-diameter bypass pipeline (Figure 170). Currently, the pipeline runs to a temporary dewatering structure, about 600 feet downstream of North Fork Dam. The temporary dewatering screen structure removes 3 cfs of screened flow from the 10 cfs bypass flow. Because flows of up to 25 cfs could pass through the 20-inch pipeline if the new ramp weir fails in the down position, the temporary dewatering structure will include an unscreened emergency overflow. In 2015, a second fish bypass pipe will be

Figure 169: Downstream Migrant Entrance Ramp Weir (CA Dept. of Water Resources)

connected to the dewatering facility from a new floating surface collector. Fish from both locations will be combined at the facility into the 18" downstream migrant pipe (McMillen 2011).

In 2011, PGE constructed a new pipeline from the temporary dewatering facility to the section of the existing pipeline about 3 miles downstream, near the Faraday Bridge. The new pipe is buried under the existing E. Faraday Road pavement, except for a short section of pipe that is placed on an elevated pier system adjacent to the road (MGH Associates 2011).

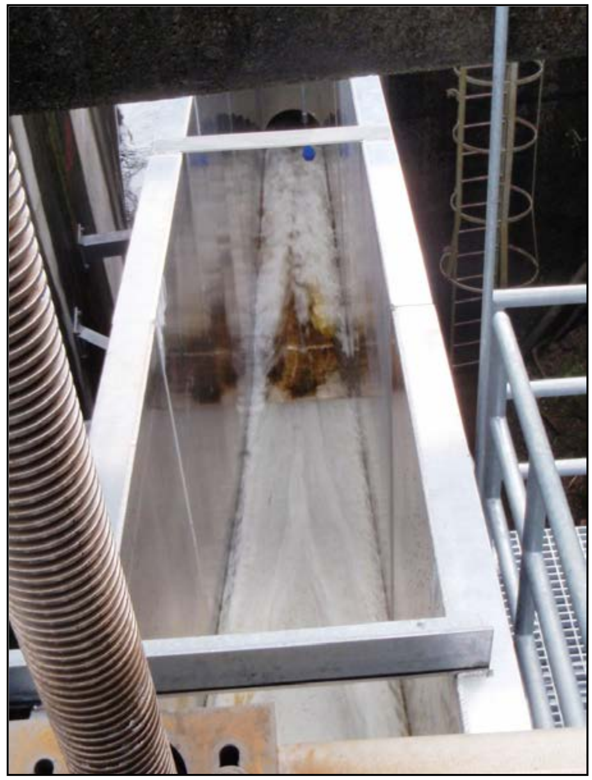

Figure 170: Downstream Migrant Entrance Transition to Pipe (CA Dept. of Water Resources)

PGE also constructed the Timber Park downstream migrant sampling facility, near River Mill Dam, in 2011 (Figure 171). ADD FIGURE NAMED McMillen_2011_Timber Park Fish Sampling Facility Drawing AS A FULL PAGE LANDSCAPE ORIENTATION The location in Timber Park takes advantage of a grade break in the migrant fish pipe which accommodates the fish sampling components while still allowing a gravity return of water into the downstream migrant pipeline. The 30-foot by 60-foot facility separates juvenile fish from adult fish and debris, and the juveniles are directed to a holding and sampling facility. Provisions for a kelt trap are provided downstream from the facility (McMillen 2011).

The downstream migrant pipe transitions from 18" to 24" approximately 260' upstream of the facility. After the 24" pipe enters the facility, it transitions to a 24" wide flume. Immediately after the transition, a gate will send fish to the main flume or the facility bypass flume. Each of these flumes has a short section of fiberglass flume, which allows for PIT Tag antennas. In the bypass configuration, the adults/kelts, juvenile fish, and debris, along with 7 cfs of flow pass a dewatering screen. Approximately 2 cfs passes through the screen and the fish and 5 cfs continue down the flume (McMillen 2011).

In the sampling configuration, fish will move down the main flume past a similar dewatering screen to a separator. The juveniles will move through the bars of the separator (Figure 172), and the adults and debris will continue down the main flume. The separator bars are made of PVC and the spacing between the bars is 1". After the separator, the juveniles are directed by flume into a holding tank. The juvenile fish are manually collected and placed in the anesthetic tank at a sampling station. After sampling, the juveniles are placed in a recovery tank before being released back into the main flume. The downstream end of the main flume connects with the bypass flume and then transitions to a 16" HDPE pipe (McMillen 2011). The fish move down about 700 feet of pipe and are released downstream of River Mill Dam (Figure 173).

From the dewatering facility near North Fork Dam to the sampling facility, flow in the downstream migrant pipe is 7 cfs and the average velocity is 6.5 fps. With the new total length of the downstream migrant pipeline being approximately 7 miles, total transit time is about 1 hour and 40 minutes (Doug Cramer, May 24, 2012).

In 2015, PGE expects to build a 1,000-cfs floating surface collector (FSC) in the North Fork forebay. Consultation on the design of the collector was initiated in 2011. A net will guide downstream migrants into the FSC for dam flows (powerhouse plus spillway) below 4,000 cfs. At flows greater than 4,000 cfs, the net will be lowered. The FSC fish bypass pipe will tie into the existing downstream transport pipe at the temporary dewatering facility (Doug Cramer, May 24, 2012).

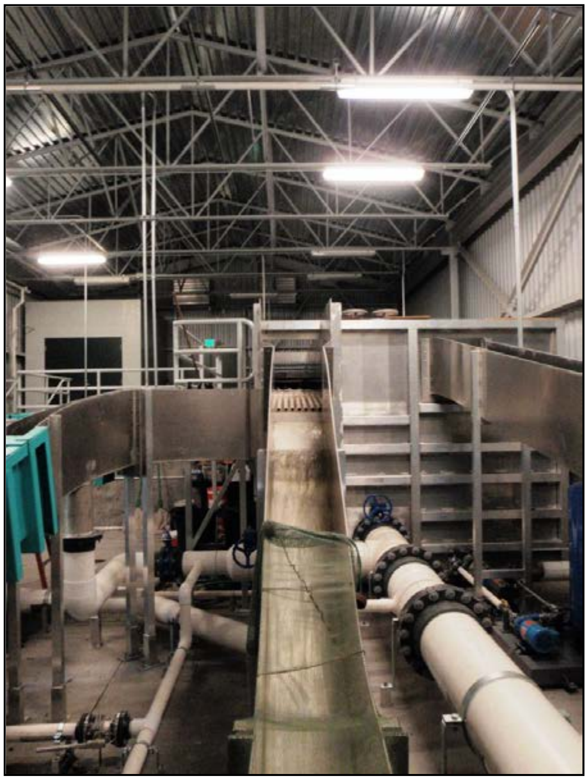

Figure 172: Timber Park Fish Sampling Facility (CA Dept. of Water Resources)

At River Mill Dam, PGE are currently constructing a 500-cfs fixed surface collector in the forebay of River Mill Dam. The collector has a "vee" configuration and one of the power intakes provides the flow. It is expected to be operational by October 2012 at an estimated cost of $15 million dollars (Doug Cramer, May 24, 2012).

Downstream migrants can also pass River Mill Dam via the spillway. The spillway is approximately 405 feet long and 85 feet high, and was concrete for about two-thirds of its length and rock for the bottom third. In 2006, the spillway was modified to increase passage survival. Modifications include a new concrete fish chute, located on the face of the spillway near the powerhouse, with a 10-foot-long by 6-foot-high Obermeyer weir installed on the spillway crest. In addition, a 40-foot-wide section of the spillway next to the fish chute, called the controlled spillway, was resurfaced and the concrete was extended to the tailrace, covering previously exposed rock. This spillway also has a 6-foot-high Obermeyer weir (Bartlett and Cramer 2006).

Figure 173: Downstream Migrant Release Pipe (CA Dept. of Water Resources)

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Pelton-Round Butte Hydroelectric Project

Location: On the Deschutes River, Oregon, approximately 40 miles north of Bend and 100 river miles from the Deschutes River's confluence with the Columbia River

Owners: Portland General Electric and the Confederated Tribes of the Warm Springs Reservation of Oregon

Dam Name: Reregulating	**Hydraulic Height:** 25	**Year Constructed:** 1958
Dam Name: Pelton	**Hydraulic Height:** 204'	**Year Constructed:** 1958
Dam Name: Round Butte	**Hydraulic Height:** 425'	**Year Constructed:** 1964

Target Species: Spring-run Chinook salmon, fall-run Chinook salmon, sockeye salmon, steelhead trout, bull trout, and Pacific lamprey

Upstream Passage: Adult collection and transport from downstream of the Reregulating Dam to Lake Billy Chinook above Round Butte Dam began in June 2012.

Downstream Passage: Fish from Lake Billy Chinook are collected at the Selective Water Withdrawal Tower fish facility just upstream of Round Butte Dam and transported by truck to below the Reregulating Dam.

Project Description

The Pelton Round Butte Hydroelectric Project consists of three dams, Reregulating, Pelton, and Round Butte, which collectively are the largest producers of electricity located entirely in the State of Oregon (Figure 174). The project is jointly owned by the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) and Portland General Electric (PGE). It is the only hydropower project in the United States to be owned by a Native American tribe and a utility (PGE 2010).

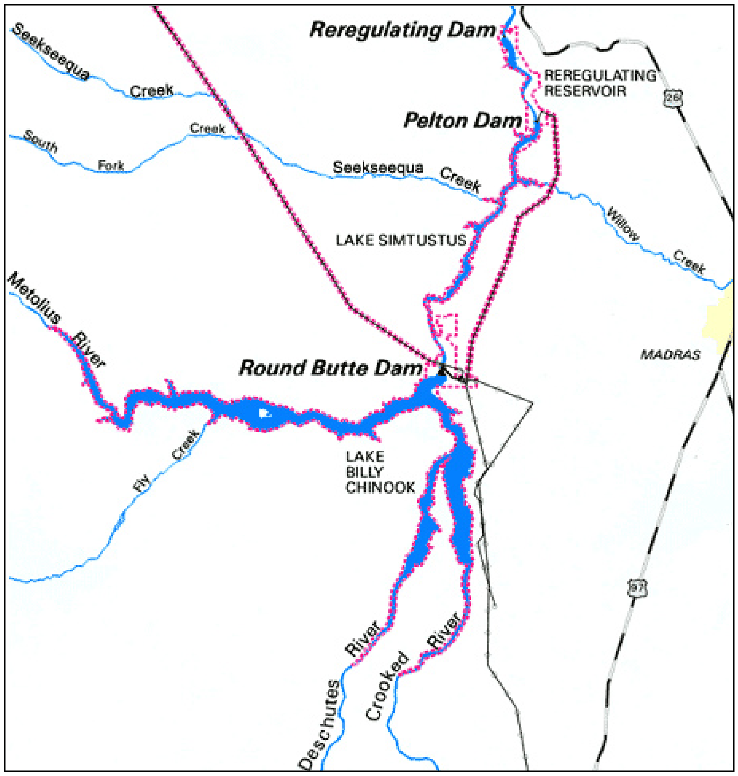

Figure 174: Pelton Round Butte Hydroelectric Project Map (Courtesy of PGE)

The CTWSRO currently own one-third of the project and are also the full owners of the Reregulating Dam. PGE and the CTWSRO have developed an agreement that protects the CTWSRO' historic and cultural resources, including historic properties, culturally significant plants, and archaeological sites. Power from the three dams is an important source of income for both entities (PGE 2010).

The Deschutes River is a major tributary to the Columbia River and produces electricity for the region and provides irrigation for nearby agriculture (PGE 2010).

Figure 175: Pelton Reregulating Dam and Pelton Ladder (Courtesy of PGE)

Figure 176: Pelton Dam and Upstream End of Pelton Ladder (Courtesy of PGE)

Pelton and Reregulating Dams were constructed concurrently and were completed in 1958. The Reregulating Dam is approximately 100 river miles upstream from the Columbia River, and is the most downstream dam in the Project (Figure 175). It is used to store the peaking flows of the two upstream dams and release regulated flows to the lower Deschutes River. The 88-foot-tall (25-foot hydraulic height) rock-fill dam is 1,067 feet long and creates 3,500-acre-foot Reregulating Reservoir that impounds 2.5 miles of the Deschutes River to the base of Pelton Dam. The powerhouse at the Reregulating Dam was constructed by the CTWSRO in 1983, and has a single bulb turbine with an 18.9 megawatt capacity (PGE and CTWSRO 2004). The dam also has four concrete spillways, each equipped with a 20-foot-wide, 14-foot-high steel gate (FERC 2005).

Pelton Dam is a 210-foot-high (204-foot hydraulic height), 965-foot-long concrete arch dam (Figure 176). The construction of the dam created Lake Simtustus, a 31,000-acre-foot reservoir which backs up 7 miles of the Deschutes River to the base of Round Butte Dam. The dam has three 16-foot-diameter, 100-foot-long penstocks, which route water to three Francis turbines with a total power generating capacity of 100.8 megawatts (PGE and CTWSRO 2004). The dam also has a concrete spillway equipped with two, 34-foot-wide, 22-foot-high steel Tainter gates (FERC 2005).

Round Butte Dam was completed in 1964 and is the most upstream development of the Project (Figure 177). It is a 440-foot-high (425-foot hydraulic height), 1,382-foot-long rock-filled embankment dam which creates the 535,000-acre-foot reservoir Lake Billy Chinook. Lake Billy Chinook impounds 9 miles of the Deschutes River, 7 miles of the Crooked River, and 13 miles of the Metolius River (PGE and CTWSRO 2004). A 1,425-foot-long, 23-foot-diameter power tunnel routes water to a powerhouse containing three Francis turbines, each capable of generating up to 82.4 MW, for a total power capacity of approximately 247 megawatts. The dam has a concrete spillway intake structure topped with a 30-foot-high, 36-foot-wide radial gate, which is connected to a 1,800-foot-long, 21-foot-diameter spillway tunnel (FERC 2005).

Construction of the Selective Water Withdrawal Tower (SWWT), located in Lake Billy Chinook approximately 700 feet upstream of Round Butte Dam (Figure 178), was completed in December 2009 at a cost of $108 million dollars. The tower's multiple-level intakes regulate the temperature of the lower Deschutes River, provide proper currents within Lake Billy Chinook, and lower the temperature of the reservoir. The tower also provides the foundation for the fish collection and transfer facility

(PGE 2010).

Figure 177: Round Butte Dam and Hatchery (CA Dept. of Water Resources)

The Round Butte and Pelton portions of the project are store and release facilities that operate in a peaking mode. Water releases from the two facilities are made during system peak electric power demand periods and are reduced during off-peak periods. The Reregulating Dam stores the water and provides steady flow releases to the river downstream. The average daily discharge from the Reregulating Dam is approximately equal to the average daily inflow to Lake Billy Chinook (PGE and CTWSRO 2004).

Figure 178: Round Butte Dam and the Downstream Fish Collection Facility (CA Dept. of Water Resources)

Under current operations, Lake Billy Chinook is held at the normal maximum water surface elevation from June 15 to September 15 each year. Project operators attempt to avoid reservoir fluctuations of more than 1 foot during this time of year due to recreational demands and the need to protect riparian resources and cultural sites along the impoundment. The lake is typically drawn down about 10 feet during the period from November to February or March, and then refilled during April and May. Lake Simtustus typically varies less than 0.75 feet on any given day, but there are days when it can fluctuate more than 3.5 feet. The Reregulating Reservoir has the greatest elevation change, with typical and maximum daily fluctuations of 20 and 27 feet, respectively (PGE and CTWSRO 2004).

The original 50-year license for the Pelton Round Butte Project was issued to PGE on December 21, 1951, and it expired on December 31, 2001. On July 30, 2004, PGE and the CTWSRO filed a Settlement Agreement that resolved various issues related to the relicensing of the Pelton Round Butte Project. The Settlement Agreement was signed by PGE, the CTWSRO, and 20 other organizations, including the USFWS, NOAA Fisheries, and the Oregon Department of Fish and Wildlife. Many agencies and organizations filed comments in support of the Settlement Agreement and no entity opposed the agreement. The project received a new license from the Federal Energy Regulatory Commission (FERC) in 2005 which incorporates most of the Settlement Agreement's proposed

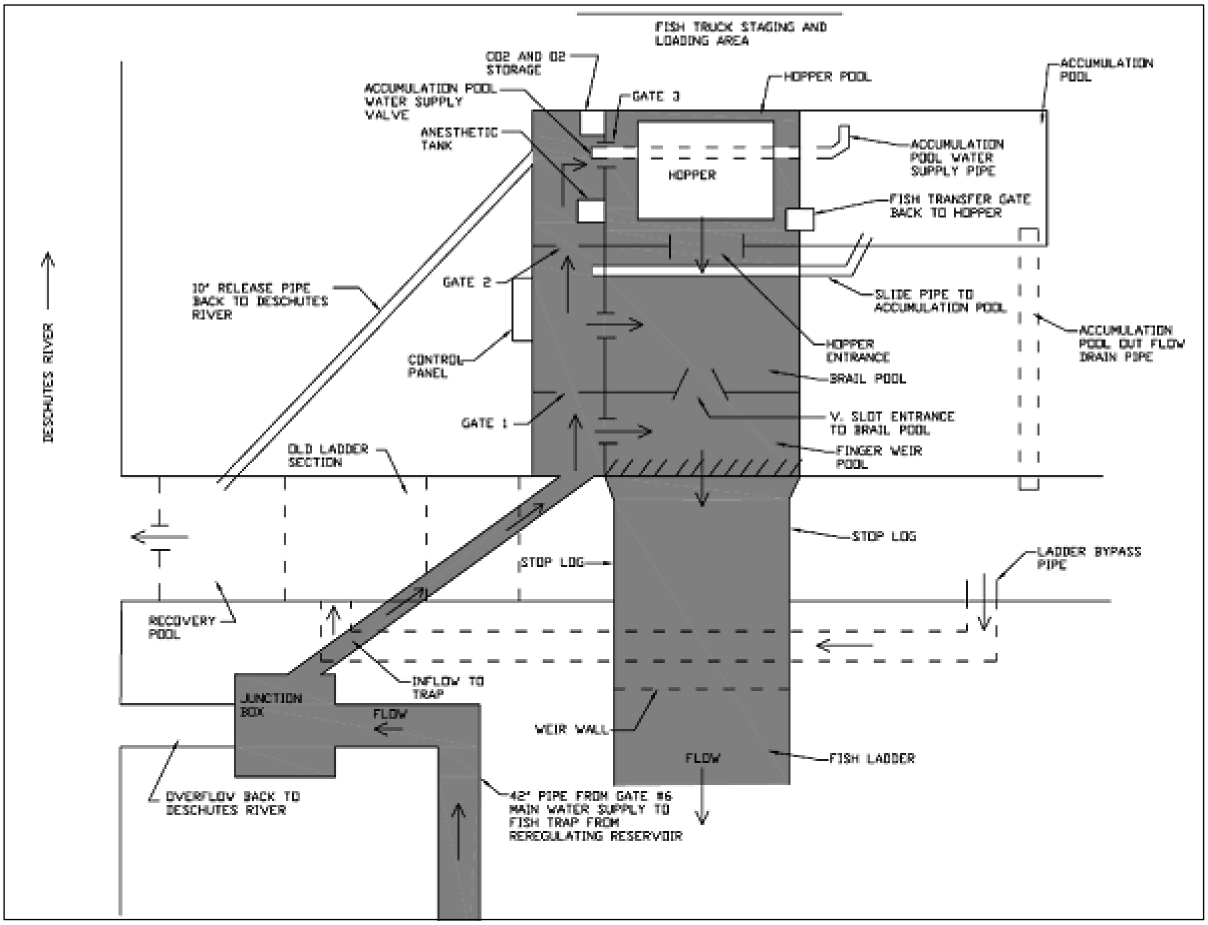

Figure 179: Pelton Fish Trap Layout (PGE and CTWSRO 2009b)

license articles (FERC 2005).

Fish Passage History

From its inception, fish passage has been an issue at the Pelton Round Butte Project, limiting the ability of Deschutes River basin anadromous fish to exist as naturally spawning, genetically diverse populations. Although the decline of salmonid species in the watershed has been caused by numerous factors, it is undeniable that the Project has created a barrier to upstream and downstream migration, and movement between major and minor tributaries. Access to over 225 miles of habitat was lost: 155 miles on the Crooked River, 30 miles on the upper Deschutes River, and 41 miles on the Metolius River (PGE and CTWSRO 2004).

Figure 180: Pelton Trap Finger Weir and Entrance Pool (CA Dept. of Water Resources)

Figure 181: Pelton Trap Brail Pool (CA Dept. of Water Resources)

At the time the Project was first licensed, maintenance of anadromous fish runs was of paramount concern for federal, state, and Tribal resource managers (PGE and CTWSRO 2004). The Project was constructed with both upstream and downstream fish passage facilities (Ratliff and Madden 2006). However, shortly after Round Butte Dam was constructed, it became apparent that the fish passage facilities were not performing as intended, primarily due to downstream migration problems in Lake Billy Chinook. The fish passage facilities were abandoned in the late 60s and early 70s, and the Project has been a barrier to migrating salmonids since that time (PGE and CTWSRO 2004).

The first Project fish facility was a fish trap, completed in August 1956 immediately downstream of the future site of the Reregulating Dam (Ratliff et al 1999). The Pelton Fish Trap (Figure 179), which is still in operation today, was built to capture upstream migrating salmon and steelhead for hauling around the construction areas of the two dams. Built in conjunction with the trap was an approximately 150-foot-long fish ladder leading directly from the river to the trap, and a fish migration barrier in the form of a wooden weir that angled downstream and across the river from just above the ladder entrance. This barrier weir guided upstream migrating fish to the entrance of the fish ladder. Water was furnished to the trap and ladder by a temporary pump station (Ratliff and Madden 2006).

Figure 182: Pelton Trap Hopper (CA Dept. of Water Resources)

The Pelton Fish Trap is a Buckley-style trap, originally composed of three concrete pools: an entrance pool (Figure 180), a brail pool (Figure 181), and a hopper pool. Fish swam upstream into the flow of water through the two lower pools and eventually ended up in the hopper pool. Once fish were in the hopper pool, the hopper (Figure 182) was raised out of the pool and lowered over a tank truck and emptied. The truck hauled the fish to a release point upstream, where it was backed into the water and released the fish into Lake Simtustus (Ratliff and Madden 2006).

Figure 183: The Lower End of the Pelton Fish Ladder (Courtesy of PGE)

From 1968 through 1972, hatchery production occurred at Oregon Department of Fish and Wildlife Hatcheries, and adults to produce eggs for these programs were collected at the Pelton Fish Trap (Ratliff and Madden 2006). In 1972, the Round Butte Hatchery was constructed at the base of Round Butte Dam, and upstream migrants for the hatchery were, and still are collected at the Pelton Fish Trap (ODFW 2010).

An accumulation pool was added to the Pelton Fish Trap in 2000, just east of the hopper pool, in anticipation of using the facility for fish passage as well as hatchery brood capture. The fish that will be loaded into a transport truck slide down a sloping pipe above the brail pool into the accumulation pool. Due to the addition of this pool, fish to be transported to different locations can be accumulated separately in either the hopper or the accumulation pool during one sorting (PGE and CTWSRO 2009b).

Because of its strategic location, the Pelton Fish Trap has been in nearly continuous operation since 1956 (Ratliff and Madden 2006). Since the termination of fish passage in 1968, more than 207,000 adult anadromous salmonids have been captured and processed at the Pelton Fish Trap with nearly half of them trucked to Round Butte Hatchery with a measured mortality of less than 0.5 percent (PGE and CTWSRO 2009b).

In April 1957, the 2.84 mile long Pelton Fish Ladder became operational (Figures 183 and 184). The Pelton Fish Ladder is a pool and weir type fishway which provided upstream passage from the Pelton Fish Trap to Lake Simtustus above Pelton Dam. At the time it was constructed, it was the longest pool-type fishway in the world with the second highest lift (230 feet). The fishway is not currently operated for fish passage, but the lowest section of fishway connects the Deschutes River to the Pelton Fish Trap (PGE and CTWSRO 2009b), and lower portions are used for the rearing of salmonid fry from the Round Butte Hatchery (ODFW 2010).

The fishway measures 10 feet wide by 6 feet deep, and it originally had a maximum flow capacity of 43 cfs (Gunsolus and Eicher 1962 in Ratliff and Schulz 1999). However, following construction,

Figure 184: Pelton Fish Ladder along Reregulating Reservoir (CA Dept. of Water Resources)

boards were attached to the weirs to reduce oscillation that reduced capacity to 36 cfs (Ratliff et al 1999). The gradient in the steeper sections of the ladder is one foot of rise for a 16-foot-long pool. Much of the fishway, however, is of a lesser gradient, with weirs spaced at irregular intervals ranging from 100 to 300 feet apart and each providing a 6 inch rise (Gunsolus and Eicher 1962 in Ratliff and Schulz 1999).

In the lower one-third of the fishway is a 2,700-foot-long canal section which is trapezoidal in section and has a very slight gradient. Flow velocity in this section, as in most of the flatter reaches of the fishway, is less than 1 ft/sec. Each weir or baffle in the fishway contains an orifice at the bottom. In the steep sections, these are 1.5 feet square and staggered alternately on either side of the fishway. In the flatter stretches, the orifices are in the center and are 2 feet square (Gunsolus and Eicher 1962 in Ratliff and Schulz 1999).

Fish enter the fish trap fishway on either side of the Reregulating Dam spillway (Figure 185). The left-bank (west) entrance is connected to the fishway by means of a tunnel under the spillway. The two branches combine in a junction pool immediately downstream of the slope of the rock-fill dam. A 400-foot-long section of ladder connects the junction pool with the Pelton Fish Trap (PGE and CTWSRO 2009b).

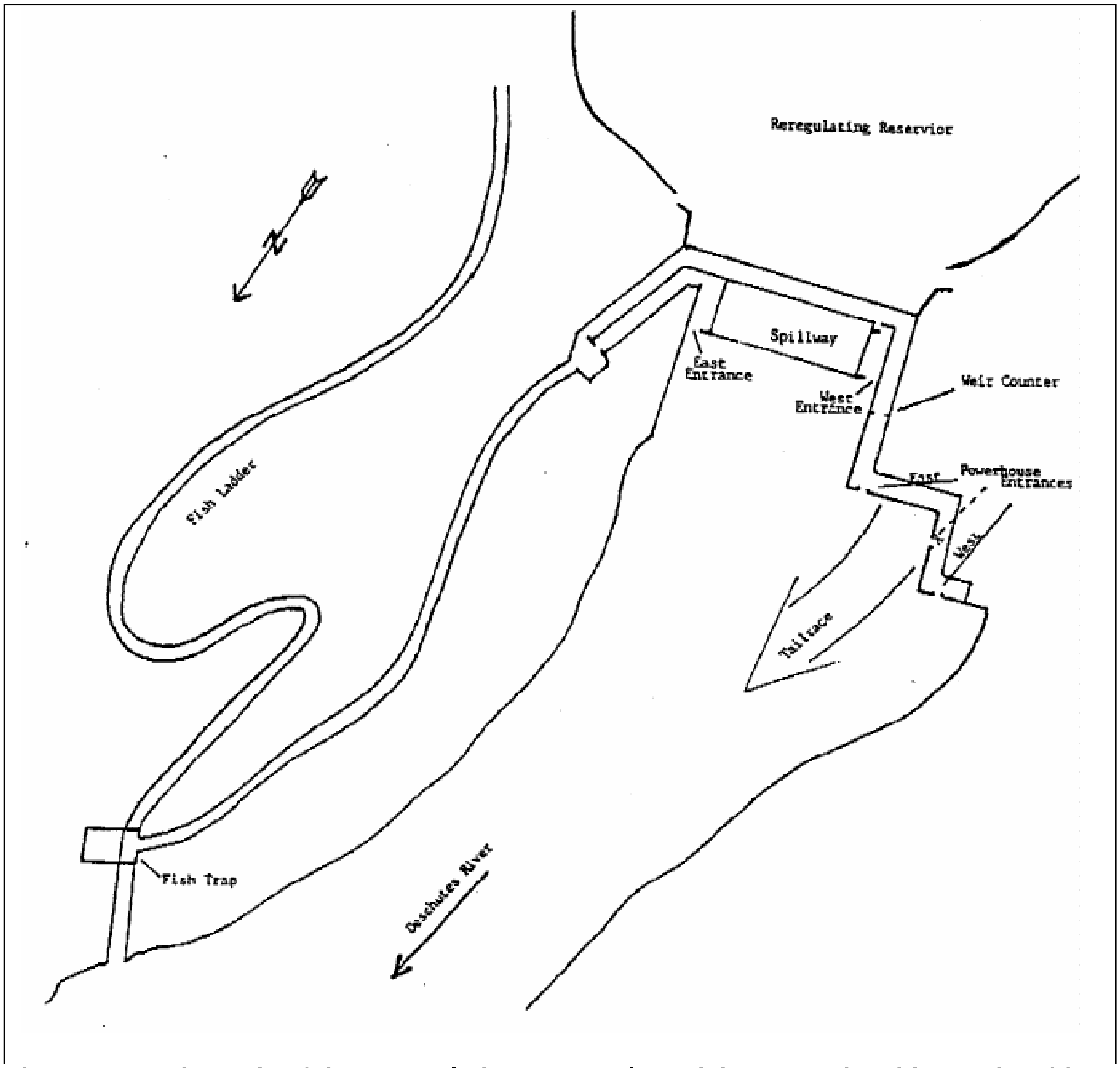

Figure 185: Schematic of the Reregulating Dam, Pelton Fish Trap and Ladder, and Ladder Entrance Locations (PGE and CTWSRO 2009b)

In 1982, the CTWSRO constructed a powerhouse at the Reregulating Dam. During normal operation, the entire discharge from the Reregulating Dam flows through the powerhouse on the left bank (west side) of the river. Three new fish facility entrances were constructed in association with the new powerhouse, all of which used pumped fish attraction water. These entrances interconnected to the lower segment of the fishway leading to the Pelton Fish Trap (PGE and CTWSRO 2009b). The middle entrance of these three entrances was closed shortly after the facility began operation due to the confusing hydraulics in the area of the entrance (Fritsch et al. 1997 in PGE and CTWSRO 2009b). Additionally, a 1987 evaluation of the two remaining new entrances showed that they were ineffective (Fritsch et al 1997 in Ratliff et al 1999). Since 1987, only the old right bank (east) entrance has been used when the Reregulating Dam powerhouse is operating (Ratliff et al 1999).

The 2.84-mile-long fishway was only partially successful at passing adult salmonids during the initial years of the Project. The exact cause of fishway rejection is unknown, but it is thought that vegetative growth in the fishway during the late spring and summer (including the ½ mile earthen canal section that develops emergent vegetation), not only changed the water chemistry, but also changed the odor fish encountered when entering the fishway. To the adult migrants that wanted to pass, the fishway smelled like a tributary of which they were not cued to (Don Ratliff, personal communication, October 7, 2010). By 1968, it became apparent that adult migrants were not ascending the fishway as designed and passage reverted back to the trap and haul system using the Pelton Fish Trap (Ratliff and Madden 2006).

After it stopped being used for fish passage, the fishway began to be used for the rearing of salmonid fry (Ratliff and Schulz 1999). It has been modified over the years and has been used as a rearing site for some of the juvenile spring-run Chinook produced at the Round Butte Hatchery. As part of the production program, hundreds of thousands of spring-run Chinook reared at the hatchery are transferred to Pelton Ladder in November. These fish over-winter and are allowed to volitionally migrate out of the fishway in the spring. The use of the fishway for rearing juvenile spring-run Chinook has proven to be a feasible and successful means for increasing adult returns. Spring-run Chinook smolts rear well in the fishway, apparently benefiting from the semi-natural rearing conditions. Rearing in the fishway takes place in its modified lower portion. The existing rearing space represents only 20 percent of the available fishway capacity suitable for rearing fish (Smith 1991). In 2011, the strategy is to rear and transfer 265,000 spring-run Chinook to the ladder in early November (ODFW 2011).

In 1964, the addition of Round Butte Dam complicated the upstream fish passage situation. Because the steep canyon walls surrounding Round Butte Dam precluded construction of a fish ladder, a tramway fish lift was constructed (PGE and CTWSRO 2004). Migrating adult salmon and steelhead that had traversed the Pelton Fish Ladder and Lake Simtustus were attracted into entrances, located at opposite ends of the downstream face of the Round Butte Powerhouse, by a flow of 200 cfs. After traveling up the fish channels inside the powerhouse, they were attracted by a small amount of water pumped through a false weir. They would travel through the water upwelling in the false weir and slide down a short apron into a 170-cubic-foot bucket. While moving down the apron, they passed an electric eye that tripped a camera and strobe, photographing each fish and activating a counter. The film was later reviewed to accurately discriminate counts between species (Ratliff and Schulz 1999).

After a certain number of fish had accumulated in the bucket, a vertical winch lifted it above the top of the dam. This tramway could be activated manually or could be automatically engaged. Once over the top of the dam, the vertical winch stopped and the haul winch moved the bucket to the reservoir side of the dam. The bucket was lowered into the reservoir and the fish were released 15 feet below the surface. In the final cycle of operation, the tramway bucket returned to its starting location below the powerhouse deck. The total cycle time was approximately 45 minutes (Ratliff and Schulz 1999).

The original downstream-migrant collection facility for Round Butte was an artificial outlet, or skimmer. It was located in Lake Billy Chinook at the east end of the dam, and was built to accommodate the majority of the potential 85 foot drawdown. It had vertical-axis traveling screens instead of a horizontal screen like the Pelton Skimmer (described below) and used four 100 cfs pumps. The vast majority of the water that entered the artificial outlet passed through the screens, but about 5 cfs carried smolts past the screens, over a weir, and through a pipe to a locking tank. At the locking tank, smolts could either be loaded into a truck and hauled downstream around Pelton and the

Reregulating Dams, or be shunted into a pipe and into Lake Simtustus. The downstream-migrant pipe was designed to be filled completely with water, so that fish rode the top of the water column down as the pipe emptied into the Round Butte Dam tailrace (Eicher 1964 in Ratliff et al 1999).

Downstream passage from Lake Simtustus at Pelton Dam, consisted of a horizontal, inclined-plane artificial outlet, referred to as the Pelton Skimmer (Figures 186 and 187). The skimmer was constructed on the right (east) abutment of Pelton Dam and used pumps to pull 200 cfs of water through a 15 foot wide screen assembly (perforated plate). The screen assembly was inclined, allowing about 6 cfs of water and downstream migrating fish to move over the end, and then through a bypass pipe into the fish ladder junction box. The smolts then entered the fish ladder and traveled down to the Deschutes River below the Reregulating Dam (Ratliff et al 1999).

As stated earlier, after Round Butte Dam was constructed it became apparent that the downstream fish passage facilities at Lake Billy Chinook were not performing as intended. This was due primarily to downstream migration problems through the reservoir. Currents from the Deschutes and Crooked rivers entered the east arm of the reservoir, and instead of flowing to the artificial outlet at the dam, most of this relatively warm water turned left to the west arm, and headed upstream over the top of the colder Metolius current. The water that did turn downstream, toward the dam, swirled in eddies with no particular direction. The migrating fish in the currents rarely found their way to the artificial outlet. This problem was reconfirmed in studies of migrating fish that carried tiny radio transmitters (PGE 2006).

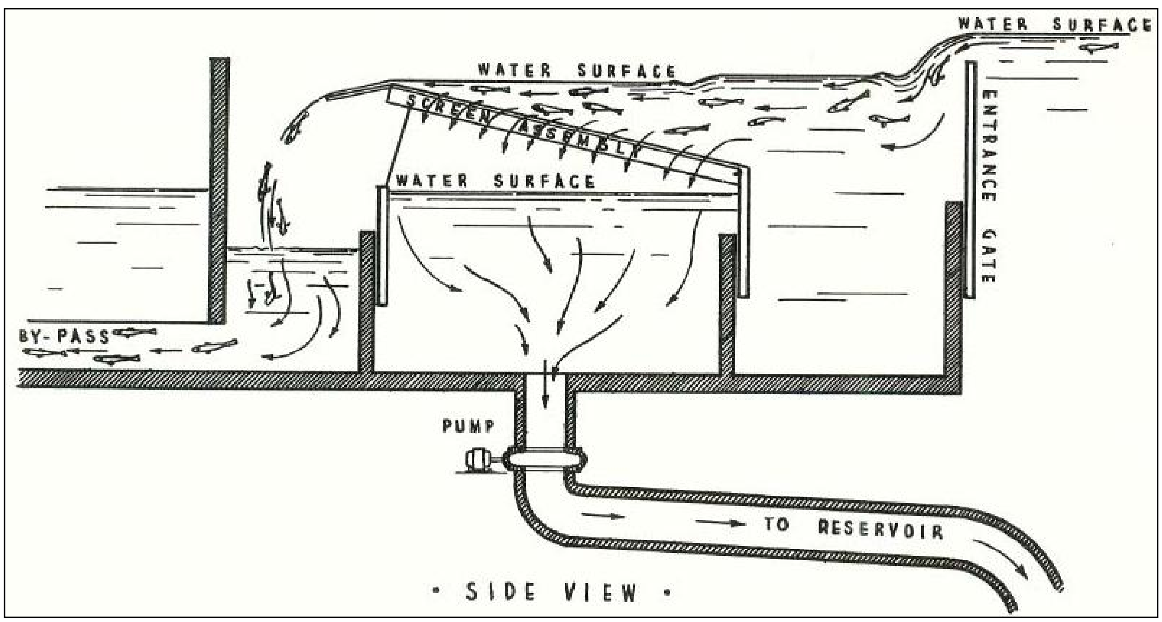

Figure 186: Pelton Skimmer (PGE 2009)

Figure 187: Pelton Skimmer (CA Dept. of Water Resources)

The Fish Commission of Oregon conducted evaluations of the Project's fish passage facilities under the supervision of a multi-agency steering committee and determined that the facilities were incapable of sustaining the runs due to problems with juvenile downstream migration. As a result, plans to mitigate fish losses through a hatchery were put into place by 1966. The downstream fish passage facilities at Round Butte Dam were taken out of service in 1969, and the Round Butte tramway and Pelton Fish Ladder were retired as fish passage facilities by 1973 (Ratliff et al 1999). Since then, the Project has been an impassable barrier to fish passage, cutting off access to historic spawning and rearing habitat upstream of the project (PGE and CTWSRO 2004).

The need to relicense the Project in 2001 led to the Settlement Agreement, which was completed in 2004. With regard to fish passage, the Settlement Agreement states that:

> The Licensees (Confederated Tribes of Warm Springs and Portland General Electric) shall implement a Fish Passage Plan to establish self-sustaining, harvestable anadromous fish runs of Chinook, steelhead, and sockeye above the Project.
>
> The Licensees shall provide for safe, timely and effective upstream and downstream fish passage of adult and juvenile life stages of spring and fall Chinook, summer steelhead, sockeye salmon, bull trout, rainbow trout, and mountain whitefish.
>
> The Licensees shall implement a three-phase fish passage program, including sequential step-by-step implementation with clearly stated targets, accomplishments, consultation, and prerequisite requirements for each phase. The three phases are Experimental, Interim, and Final.
>
> (i) The Experimental Passage Phase is the circa 2004 stage of fish passage at the Project and includes but is not limited to modeling of currents in and water withdrawal from Lake Billy Chinook, conceptual designs for downstream passage facilities at Round Butte Dam, Pelton Fish Trap improvements, juvenile migration

studies in Lake Billy Chinook, fish health monitoring, approval of the Fish Health Management Program, and stock selection of species.

(ii) The Interim Passage Phase shall include investigations of fish passage methods and construction of selective water withdrawal facilities and temporary and permanent downstream passage facilities at Round Butte Dam. Actions and adaptive management studies for this phase shall include but are not limited to:

(1) Evaluation of the Round Butte Dam selective water withdrawal system;

(2) Hydraulic and biological evaluation of the Round Butte Dam temporary and permanent downstream collection and fish handling facilities;

(3) Biological evaluation of the adult fish release facility;

(4) Modification and reactivation of the Pelton Dam historical downstream migrant facility;

(5) Conducting predation studies in Lake Billy Chinook; and

(6) Conducting fish health monitoring and evaluation.

(iii) The Final Passage Phase shall include actions and adaptive management studies for feasibility determination, development, and construction of permanent upstream fish passage facilities, contingent on the achievement of successful downstream passage at the Project.

These actions and studies shall include:

(1) Reactivation and evaluation of the Pelton Fish Ladder for volitional upstream fish passage;

(2) Construction of new ponds or facilities to rear juvenile spring Chinook or construction of a new ladder to retain or replace existing spring Chinook rearing capacity;

(3) Construction of a new fish ladder, or other volitional upstream fish passage facility, at Round Butte Dam; and

(4) Continued monitoring of the success, and improvement if necessary, of fish passage for all species.

The Licensees shall conduct effectiveness monitoring, annual work plans, and a phased approach that includes:

(i) A specific schedule of timelines, including testing and verification studies, study results and decisions;

(ii) Analysis of self-sustaining harvestable anadromous fish runs with the use of life cycle models and evaluation of passage efficiencies and survival estimates for the different life history stages of each species;

(iii) Establishment of performance measures and monitoring success towards achieving performance measures;

(iv) Evaluation of spawning, rearing, and movement of re-introduced fish species;

(v) Evaluation of movement of native resident fish species upstream and downstream through Project facilities and reservoirs;

(vi) Trap and haul of adult fish subject to the long-term goal of volitional upstream fish passage, which will eventually require construction, evaluation, and monitoring of upstream collection facilities, if determined to be feasible;

(vii) During initial implementation, capturing and marking out migrating smolts from above the Project so that they may be differentiated from other returning adults in subsequent years;

viii) Continued reservoir and drogue studies to refine operations and implementation of structural changes that will assist juvenile migration through Lake Billy Chinook;

(ix) Annual evaluation of stock performance success via outmigrant escapement and adult returns, including periodic evaluation and validation of the model results to determine the efficacy of the passage program;

(x) Preparation of design specifications for fish passage facilities in consultation with the Fish Committee and with approval by the appropriate Fish Agencies pursuant to their respective statutory authorities; and

(xi) Fish passage standards and monitoring, evaluation and reporting requirements.

The Licensees shall provide that upstream and downstream passage facilities will be functional during all months of the year to provide safe, timely, and effective passage for resident and anadromous fish.

The following table summarizes the criteria and goals for safe, timely, and effective downstream and upstream passage for fish

Table 11: Criteria And Goals For Safe, Timely, And Effective Downstream And Upstream Passage

Item	Criteria and Goals
1. Screen hydraulic criteria	NOAA Fisheries smolt criteria

2. Downstream passage facility survival (from Round Butte collection to lower Deschutes River release point)	93 percent survival for temporary facility during first five years of operations 96 percent smolt survival for permanent facility
3. Upstream passage facility survival (from lower Deschutes River collection point through adult release facility)	95 percent during first five years of operations 98 percent after five years
4. Round Butte reservoir downstream passage associated with temporary passage facilities	>50 percent of a statistically significant sample of tagged steelhead or spring Chinook outmigrants from any Project tributary averaged over four years of study
5. Round Butte reservoir downstream passage associated with permanent collection facilities	>75 percent survival of PIT-tagged smolts calculated as a rolling 4-year average during the first 12 years

The Settlement Agreement parties have agreed that unless feasibility studies find that volitional passage facilities should not be built, based on pre-determined criteria specified in the Proposed License Articles, the Licensees will install volitional upstream passage facilities following the installation of permanent downstream passage facilities at Round Butte Dam and the achievement of downstream survival targets.

Following the installation of the permanent downstream passage facilities at Round Butte Dam and within 24 months of when the downstream survival targets in the Fish Passage Plan for Lake Billy Chinook have been achieved, the Licensees shall conduct a study and provide a report on the feasibility of volitional upstream passage. Factors to be addressed in the study, shall include, but not be limited to:

(i) Engineering feasibility;

(ii) Biological effectiveness, including but not limited to risk of disease transfer and stray rate for out-of-basin fish;

(iii) Cost;

(iv) Performance, including efficiency, of the existing trap-and-haul operation.

Following submission of this report, the Licensees shall prepare a plan to implement volitional upstream passage at the Project, which shall include appropriate testing and verification studies, unless the appropriate Fish Agencies determine pursuant to their respective statutory authorities that volitional upstream passage facilities should not be installed because:

(i) Oregon Department of Fish and Wildlife (ODFW) and Confederated Tribes of the Warm Springs Reservation Branch of Natural Resources (CTWS BNR) have determined that the risk of disease transfer is too great,

(ii) The stray rate for out of basin fish is not acceptable,

(iii) Volitional upstream passage is infeasible, as determined utilizing the results of the feasibility study, or

(iv) It is preferable, due to concerns with the state of the art for volitional upstream passage facilities combined with high efficacy of trap and haul operations, to continue the trap-and-haul operation for some additional specified period of time.

The plan shall be completed within 24 months of the Fish Agencies' determination that volitional upstream passage should proceed. Upon approval by the Fish Agencies, the Licensees shall file the plan with FERC. Upon FERC approval, the Licensees shall implement the plan.

Upon any determination that volitional upstream passage should not be installed, the Licensees shall, within six months of such determination, file with the FERC a plan to continue trap-and-haul operations for a specified number of years. During any such continued trap-and-haul operation, the Licensees shall continue to monitor survival and shall take any feasible measures or implement modifications within their control to the trap-and-haul facilities that are necessary to comply with the agreed upon survival standards. Upon FERC approval, the Licensees shall implement the plan.

Current Fish Passage

Current Upstream Passage

Since 2007, steelhead fry and spring-run Chinook fry from Round Butte Hatchery have been annually released upstream of Lake Billy Chinook. Fry will be released every year until adults start being transported to the upper watershed (PGE 2010).

In May 2007, approximately 174,000 steelhead fry were released into Whychus Creek, a tributary to the upper Deschutes River (PGE and CTWSRO 2008).

In May and June 2008, over 523,000 steelhead fry were released into Whychus Creek and streams in the Crooked River basin (PGE and CTWSRO 2009a).

The steelhead production goal for 2009 was 286,000 fry to be released into Whychus Creek and 415,000 to be released into the Crooked River basin during May. Because of lesser than expected culling and losses due to disease, actual 2009 releases were significantly larger with a total of about 832,000 fry released (PGE and CTWSRO 2010).

In May of 2010, over 610,000 steelhead fry were released into the upper watershed (Don Ratliff, personal communication, October 7, 2010).

Spring-run Chinook fry releases first occurred in February 2008, with approximately 140,000 out-planted into the upper Metolius Basin (PGE and CTWSRO 2009a).

The spring-run Chinook fry release goal for 2009 was 277,000, to be released into Metolius Basin streams, Whychus Creek, and the Crooked River below Bowman Dam. However, because of lower than expected losses, the actual releases were larger, with a total release into the three watersheds of about 602,000 fish (PGE and CTWSRO 2010).

In February of 2010, over 525,000 spring-run Chinook fry were released into the upper watershed (Don Ratliff, personal communication, October 7, 2010).

PGE's plan is to only pass salmon and steelhead back upstream that originated there from the fry releases. PGE are attempting to capture and mark (a right-maxillary only mark) all potentially anadromous fish that are captured at the new fish facility at Round Butte Dam. In late 2010, Don Ratliff of PGE stated, "One of the bench marks to demonstrate that we do have a facility capable of passing fish out of the reservoir was to capture at least 50% of a group of steelhead or Chinook smolts from one tributary. We narrowly achieved that goal with spring Chinook from the Crooked River. When adults are allowed to be passed, they will be sorted from hatchery and lower Deschutes wild fish by the right-maxillary mark, placed in a truck, and released at the Round Butte Adult Release Facility" (Personal communication, October 7, 2010).

An upstream release facility for adult migrants, constructed on the shoreline of Lake Billy Chinook, will allow them to be released safely into the hypolimnion of the reservoir during the summer (Figure 188). Design of the facility was completed during 2009 and construction was completed during a special reservoir drawdown period in late 2010. The facility consists of a concrete vault positioned in the reservoir near the shore with an adjacent truck access point. Fish will be released from the

Figure 188: Adult Release Facility (CA Dept. of Water Resources)

transport truck into the vault and an opaque cover on a roller will be pulled over the top of the vault. Fish will volitionally swim out of the vault through the release pipe which will extend approximately 30 feet below the surface of the reservoir (PGE and CTWSRO 2009b).

Upstream passage of adult migrating salmonids began on June 8, 2012, with 6 spring-run collected at the Pelton Fish Trap and released into Lake Billy Chinook (PGE 2012). These fish were planted as fry above Lake Billy Chinook and migrated downstream into the fish collection facility.

Current Downstream Passage

Most of the following is from PGE's Pelton Round Butte Project, Downstream Fish Facilities, Operation and Maintenance Plan, Appendix A, Description of Downstream Facilities by System (2009). References to other sources will be noted.

In December 2009, the two-year construction of the SWWT and its associated fish passage facility was completed (Figure 189). The fish collection facility sits at the top of the SWWT and captures downstream migrant salmonids attempting to emigrate from Lake Billy Chinook. After capturing the fish, it separates them into four size categories, and distributes them to holding, processing, release, and/or loading facilities (Figure 190).

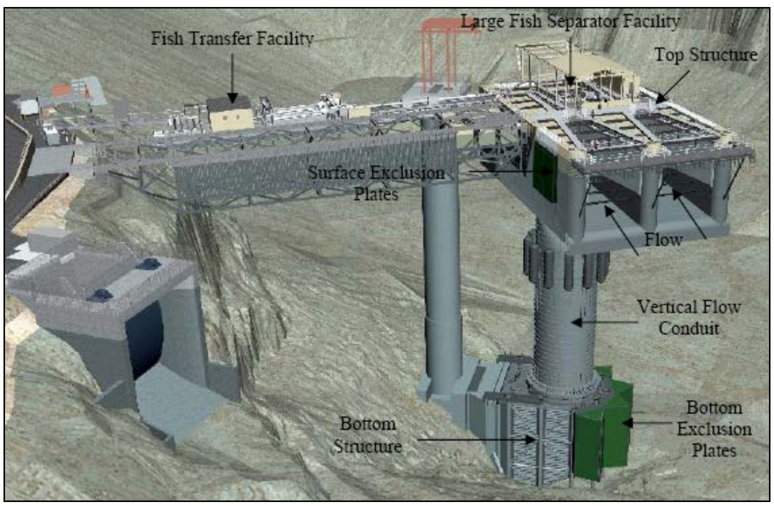

Figure 189: Selective Water Withdrawal Tower and Fish Transfer Facility (PGE 2009)

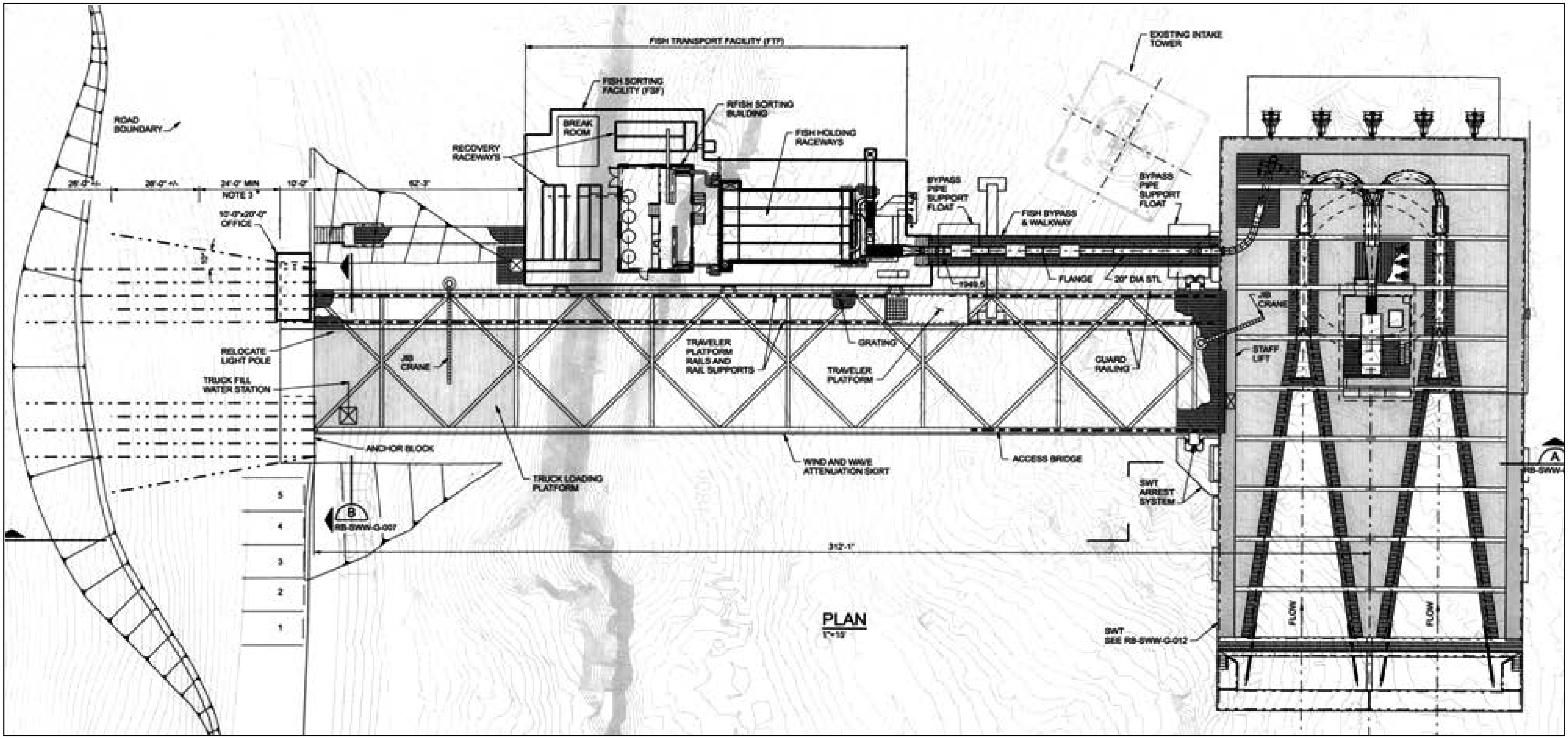

Figure 190: SWWT and Fish Transfer Facility Plan View Drawing (Designed by CH2MHill – Drawing courtesy of PGE)

During the February through June primary downstream migration period, almost all the water used for power generation at Round Butte Dam will be withdrawn from the surface of the reservoir through the two fish screen bays (Figures 191 and 192). The primary v-screens, named for their “v” shape, and secondary screens exclude fish while allowing up to 99 % of the water to flow through the screens and into the powerhouse intake.

Each fish screen bay is 40 feet wide and 45 feet tall. The maximum design flow is 3,012 cfs into each entrance, with the capability of adding an additional 500 cfs through the outside wall of each bay (for a total of 3,512 cfs for each bay and 7,024 cfs maximum surface withdrawal). At the maximum design flow, the water velocity will be 1.7 fps at the entrance, accelerating to 2.5 fps at the beginning of the

Figure 191: Downstream Collection Facility - Fish Screen Bays (CA Dept. of Water Resources)

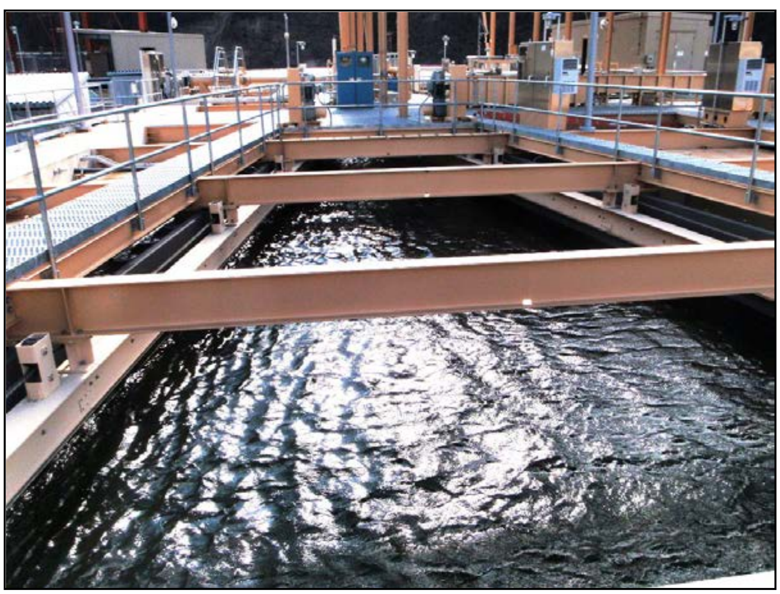

Figure 192: Downstream Collection Facility - Fish Screen Bay (CA Dept. of Water Resources)

screens, 3.5 fps at the downstream end of the primary screens, and 6.7 fps in the fish capture channel. Both the “v” shape of the side walls and the upward sloping bottom of the bays are designed to increase water velocity throughout the screen length. The facility was designed to meet the smolt approach velocity criteria of 0.8 fps. The screens are made of 60% porosity bar screen with 3/8 inch slots aligned vertically and are cleaned with horizontal-moving vertical brushes.

Figure 193: Secondary Fish Screen Channel and Cleaning System (CA Dept. of Water Resources)

The secondary screens are located downstream of the primary v- screens and reduce the flow down to 30 cfs for each channel. The sides of the secondary channel are parallel and only 2.5 feet apart and the screens are made of 60% porosity bar screen with 3/8 inch slots aligned horizontally. The secondary screens are cleaned with horizontal brushes that move vertically (Figure 193).

After the secondary screens, the two channels (one from each primary bay) converge and the combined 60 cfs enters the tertiary screen reach. The tertiary screens are constructed of 57.3 % porosity bar screen with 1/8 inch slots, and reduce the flow from 60 cfs down to 12 cfs. These screens are cleaned with a water jet system.

Immediately downstream of the tertiary screen reach, the remaining water, fish, and debris move over a control weir that is integrated with a large fish separator (Figure 194). The large fish separator is a combination wet-dry separator designed to exclude salmonids larger than about 15 inches. Fish less than about 15 inches pass with water through the separator bars (wet) and are pumped to the fish transfer facility. Larger fish slide along the bars out of the water (dry), are processed, and then released back into the reservoir.

Figure 194: Large Fish Separator (CA Dept. of Water Resources)

According to Don Ratliff of PGE, steelhead kelts are not much of a concern for downstream passage, because “repeat spawning of Deschutes Steelhead hardly ever happens because the fish have been in the river so long, and are in such poor condition when they spawn that physically, it would be very

Figure 195: Hidrostal Fish Pump (CA Dept. of Water Resources)

difficult for them. Also, they need to move downstream through two mainstem Columbia River dams, and then lay out an extra year to gain enough weight and fat reserves to spawn again" (Personal communication, October 7, 2010).

After passing through the bars of the large separator, the 12 cfs of remaining water and fish less than about 15 inches long are pumped up about 15 vertical feet to and elevation 7 feet above the normal reservoir surface level using a Hidrostal 20 inch helical fish pump (Figure 195). The fish are then routed to a transfer facility via a pipe supported by a floating bridge. In the pipe, two PIT-tag detectors read any PIT-tags that are being carried by the fish. PIT-tagging evaluates reservoir passage efficiency for smolts from the tributaries and estimates the number and timing of recaptures from fish that are released back into Lake Billy Chinook.

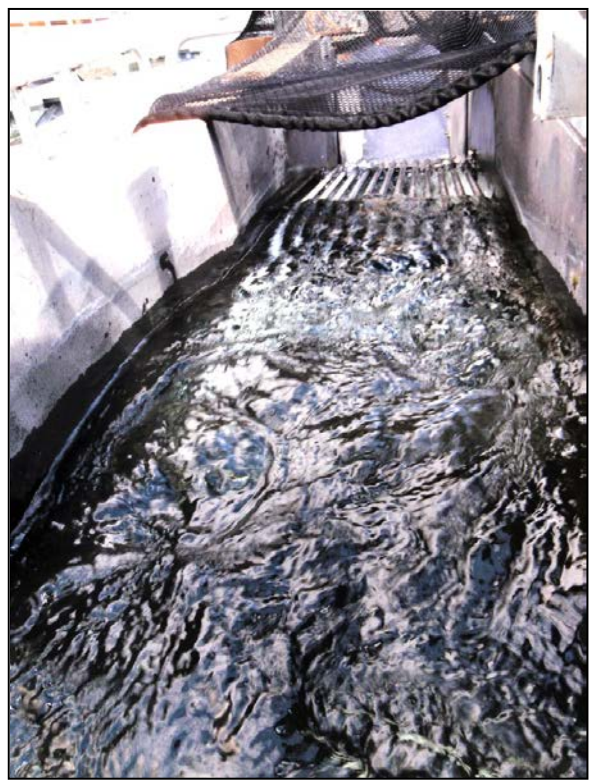

Figure 196: Medium Fish Separator (CA Dept. of Water Resources)

At the fish transfer facility, the flow is reduced and fish are separated two more times by size, using medium and small fish separators, before they enter the holding raceways. The medium wet-dry fish separator is similar to, but smaller than, the large fish separator (Figure 196). The small fish separator is a wet only separator which is smaller than the large and medium fish separators. Small fish that cannot swim through the gaps in the bars (mostly yearling

Figure 197: Holding Raceways with Fish Processing Building in Background (CA Dept. of Water Resources)

anadromous salmonid smolts) pass off the end of the bars and into the small fish flumes, which route them to the raceways. Smaller salmonid fry that swim through the bars of the small fish separator are discharged back to the reservoir.

The small- and medium-sized fish in the holding raceways (Figure 197) are processed (Figure 198) and transferred to the proper recovery raceway or experimental tank. From the recovery raceways, fish can be released back to the reservoir or loaded by hopper onto a truck for transport (Figure 199). In general, each hopper load consists of half the capacity of a recovery raceway. Three hopper loads are

Figure 198: Fish Processing (CA Dept. of Water Resources)

Figure 199: Fish Loading (CA Dept. of Water Resources)

Figure 200: Fish Release Pipe (CA Dept. of Water Resources)

used to load one truck nearly to capacity. The fish are transported to the Lower Deschutes River Juvenile Release Facility is located on the east bank of the river a short distance downstream from the Reregulating Dam and just upstream of the Pelton Fish Trap. The fish are released through a short section of pipe which attaches to the back of the transport truck (Figure 200). Fish exit the release pipe in the main current about 12 feet from the shoreline.

Downstream migrants at the fish transfer facility can also be transported, during the off-migration period (August through January), by truck to the Lake Simtustus Juvenile Release Facility. The facility is located on the east bank of the lake a short distance downstream from the Round Butte Dam powerhouse. Fish exit the pipe into deep water in the main current 10 to 15 feet from the shoreline. The purpose of moving these fish into Lake Simtustus instead of the lower Deschutes River is because many of these fish are kokanee-sockeye. While rearing, these fish require lentic habitat which can be provided by the reservoir (Ratliff et al 2009).

PGE and the CTWSRO agreed that if these juvenile, potentially anadromous salmonids are moved into Lake Simtustus, they would operate the historic Pelton Skimmer at Pelton Dam. The skimmer would be operated during the primary migration period (February through July) to capture and safely move these juvenile fish to the lower Deschutes River during the period they normally migrate to the ocean. After negotiating the 7 miles of Lake Simtustus, the downstream migrants will encounter the skimmer (described earlier in the history section) located near the right-bank abutment of Pelton Dam. The skimmer will use a net to guide fish moving down the reservoir along the west bank over to the east bank and skimmer before they encounter the dam. It will have a float line that keeps the top on the net on the surface, and a lead line which holds the net nearly vertical, extending down about 40 feet. After entering the skimmer and passing over the perforated plate, fish will move into a sump from which they exit into a holding pool until processed. After processing, fish are piped into a transport truck that will take them to the Lower Deschutes Juvenile Release Facility (Ratliff et al 2009).

Downstream juvenile fish passage was scheduled to begin from the Round Butte Dam Fish Transfer Facility in mid-April 2009. However, when contractors were assembling the major components of the SWWT, the 40-foot-diameter vertical flow conduit separated and a major part of it fell to the bottom of the reservoir. Because smolts were actively migrating down the tributaries when construction was postponed, these fish were trapped and transported to the lower Deschutes River. During late April and early May 2009, a total of 692 spring-run Chinook smolts, 831 kokanee/sockeye smolts, and 68 steelhead smolts were captured, marked with a right maxillary clip, and transported to the lower Deschutes River and released (PGE and CTWSRO 2009a).

The downstream migrant fish collection facility started operation in December 2009 (PGE and CTWSRO 2009a). In 2010, more than 125,000 fish had been captured at the fish transfer facility, including over 25,000 age 2 and older kokanee. Over 100,000 were juvenile anadromous fish, including 50,000 sockeye salmon, 44,000 spring-run Chinook salmon and 7,700 steelhead smolts, were transported to the Lower Deschutes River Juvenile Release Facility to continue their migration to the Pacific Ocean (PGE 2010). From January through mid-November 2011, more than 225,000 sockeye salmon, 175,000 age 2 and older kokanee, 30,000 Chinook salmon, and 10,000 steelhead smolts had passed through the facility (PGE 2011). Survival through the collection facility has been very good (Table 12), with all species having survival rates greater than 96% in 2010 and 2011, with the exception of kokanee in 2011 (Ratliff 2012).

Table 12: Fish Survival through the Downstream Collection Facility (Ratliff 2012)

	2010	2011
Chinook	98.5%	98.4%
Sockeye	97.7%	97.7%
Steelhead	98.4%	98.6%
Kokanee	96.7%	91.1%
Bull Trout	97.9%	98.3%

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Ireland

Ardnacrusha Hydroelectric Project

Location: On a canal connected to the River Shannon, Ireland

Owner: Electricity Supply Board (ESB) of Ireland

Dam Name: Ardnacrusha **Hydraulic Height:** 94’ **Year Constructed:** 1929

Target Species: Atlantic salmon, European eels

Upstream Passage: Borland-MacDonald fish lock, trap and haul, fish ladder on Parteen Weir

Downstream Passage: Turbines, fish ladder on Parteen Weir

Description

The hydroelectric power plant in Ardnacrusha was originally referred to as The Shannon Scheme. It is Ireland’s largest hydroelectric scheme and is composed of three vertical-shaft Francis turbine generators and one vertical-shaft Kaplan turbine generator. The system operates over an average head of 94 feet. During the 1930’s, Ardnacrusha’s power plant supplied nearly 90% of Ireland’s electricity needs, however, it currently only accounts for less than 3% (ESB 2006). An aerial view of Ardnacrusha Dam and the power plant can be seen in Figure 201.

The River Shannon is the longest river in Ireland with a total main channel length of 225 miles. Flow is diverted from the River Shannon at Parteen Weir, which was built across the channel to regulate flow and divert water into the headrace canal. The headrace canal is 7.8 miles long and is used to convey a significant portion of the River Shannon to the power plant at Ardnacrusha Dam. An intake built across the canal entrance also helps control flow into the canal. After water passes through the penstocks and turbines at Ardnacrusha power plant, it is discharged to the 1.5 mile long tailrace and back to the river downstream at Parteen-a-Lax. A map of the system is displayed in Figure 202. The maximum capacity of Ardnacrusha hydroelectric power plant is 14,125 cfs with a mean annual discharge of 6,215 cfs. The dam was originally built with locks for boat navigation.

Figure 201. Aerial view of Ardnacrusha hydroelectric power plant in Ireland. (Courtesy of ESB)

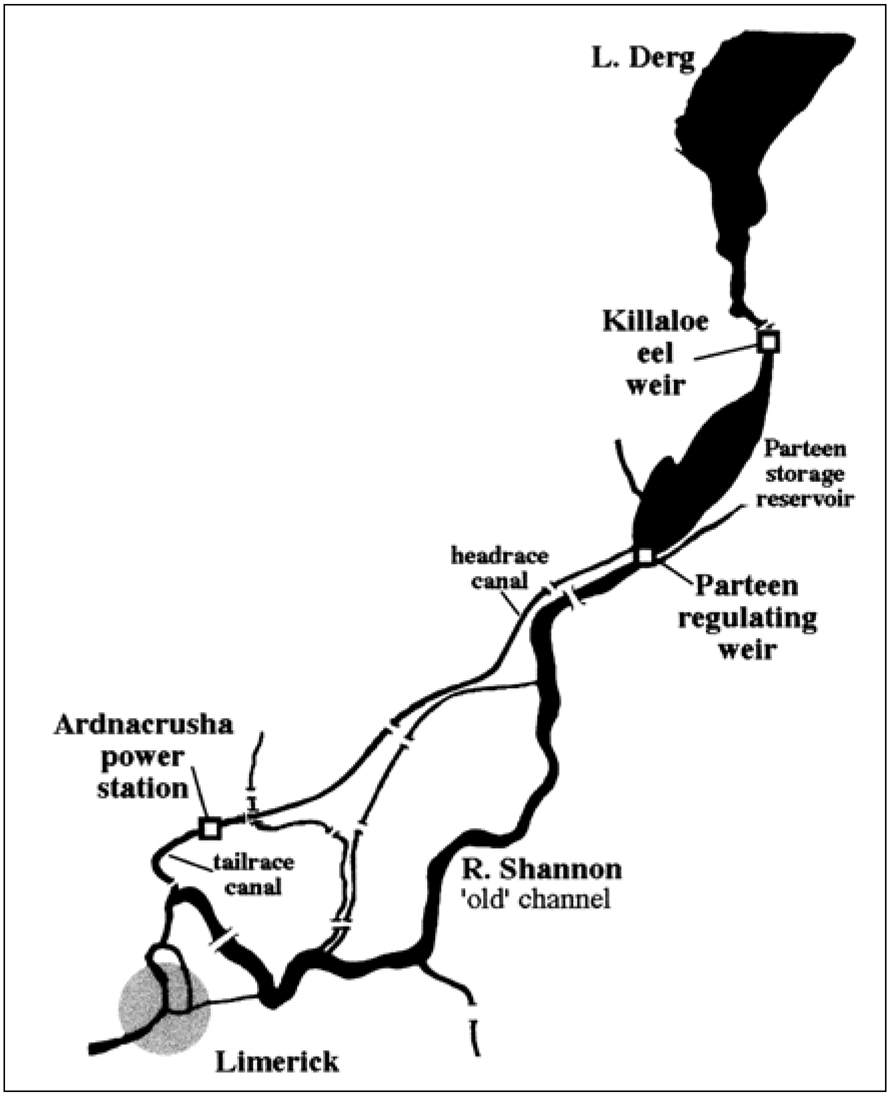

Figure 202. Map of Shannon River showing Ardnacrusha (source: Cullen 2000)

Fish Passage History

When the hydroelectric power plant was initially built, there was no upstream or downstream fish passage facility at Ardnacrusha Dam. Parteen Weir was not built with a downstream passage facility; however, a pool and weir fish ladder for upstream passage in the main river channel was part of its original construction. The reduction in water flow in the natural river channel, due to flow being diverted into the headrace canal towards the power plant, encourages more fish to migrate towards the headrace canal. There currently is a requirement that the ESB allow a minimum of 10 m3/s (353 cfs) of flow to the main river channel; the majority of this water passes through a 600 kW turbine at Parteen Weir, the remaining water feeds the fish ladder (Mccarthy et al 2008). Most of the flow in the main river is diverted into the headrace for power generation. During periods of high flow additional water may be allowed down the main river channel. When this occurs it is called “spillage”. Due to the large reduction in flow down the main river channel, many areas of the channel became dry resulting in a loss of salmonid spawning habitat. Atlantic salmon and European eels are the main species of concern in the system.

In 1959, a hatchery unit was constructed adjacent to Parteen Weir. The hatchery was expanded in 1970. After a renovation that started in 1997, the hatchery can now incubate up to 4 million salmon ova. The primary goal of the hatchery is to assist in the recovery of wild salmon upstream of Parteen and Ardnacrusha and also to educate the public. There is an education center on site that provides tours of the facility. The two Atlantic Salmon types that are bred and reared separately at the facility are grilse (or one-sea winter fish) and multi-sea winter fish. (ESB 2006)

Upstream Passage

There were no fish passage facilities at Ardnacrusha Dam until a 112 foot high Borland-MacDonald fish lock was constructed in 1959 to provide upstream passage of adult salmon. This is the primary method for upstream fish passage. The average working head is approximately 94 ft. Figure 203 displays a sectional view of the Ardnacrusha fish lock. The lock at Ardnacrusha Dam is different from the typical Borland lock because it has a vertical cylindrical chamber as opposed to the typical sloping chamber. Clay's 1995 book, Design of Fishways and Other Fish Facilities, has a good description of Ardnacrusha's fish lock operation:

> Fish enter the base of this cylinder or shaft, which is 15 ft in diameter, and are raised to forebay level as the shaft fills [with water] after the downstream gate is shut. They then enter the headrace canal by means of a horizontal open channel spanning the distance from the top of the cylindrical shaft to the top of the dam. The flow, which attracts the fish into the entrance to the lock at the base of the dam, is supplied by a 27-in.-diameter pipe leading from the horizontal open channel near the top of the main shaft. This pipe branches as shown in [Figure 3 in this document], with one branch supplying water at the base of the shaft through a disperser and the other discharging through nozzles outside the entrance gate to attract fish. There does not appear to be any bypass valve similar to that in the standard Borland fish lock … but it is assumed that when the fish rise to the surface of the water in the main shaft, they are encouraged to swim out of it into the headrace by the velocity induced in the horizontal channel by the discharge through the 27-in.-diameter pipe.
>
> The cycle of operation for the Ardnacrusha fish lock is stated as 4 h, with 2 h for collecting fish in the horizontal chamber and approximately 70 min at the full stage, when the fish are passing from the lock into the headrace. This cycle is shortened to 2 h during the peak of the eel migration, which is extremely heavy. (Clay 1995)

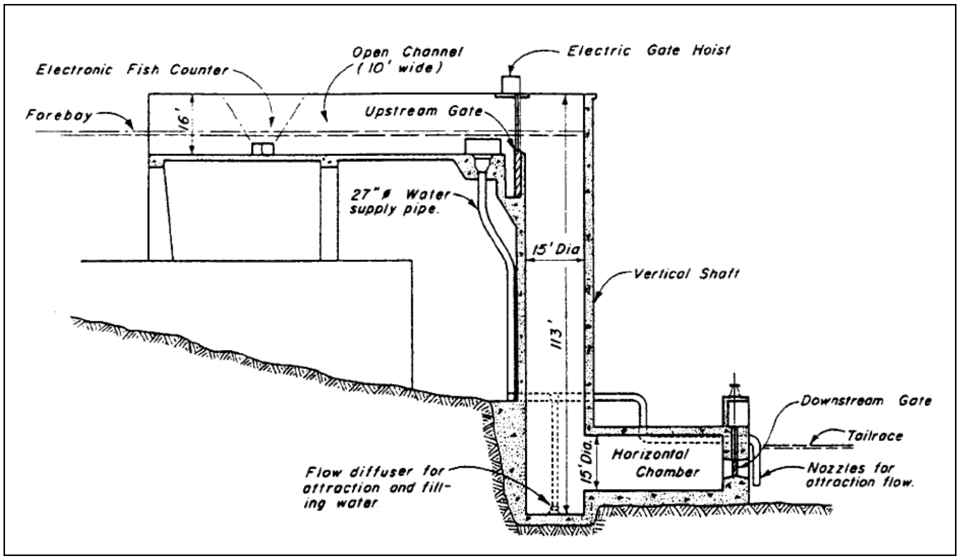

Figure 203. Sectional view of the vertical shaft fish lock in the Ardnacrusha Dam on the River Shannon in Ireland (Figure 4.2 in Clay 1995).

Adult salmon numbers are assessed by a Vaki Riverwatcher fish counter located at the upstream exit of the fish lock at Ardnacrusha Dam, as well as with an adult salmon trap on a pool in the Parteen Weir fish ladder. It has been found that most salmon utilize the fish lock in the late afternoon and evening. For the River Shannon, there is a target escapement of 2,000 salmon, however recent years have been below this target. For 2006, a total of 1,357 adult salmon were recorded ascending the Lower River Shannon, with only 24% of these being wild fish, which is the lowest number on record. Of the total adult salmon ascending, 102 wild salmon and 26 reared salmon were recorded ascending the fish lock. An additional 2 salmon were of indeterminate origin. (ESB 2006)

An article in Hydrobiologia by McCarthy et al (2008), describes observations of eels passing via the fish lock:

> Observations made in 1994–1997, by analysis of video records of 4493 lift cycles, indicated that yellow eels (10–30 cm) constituted about 25.4% by number of fish passing through the Borland lift at Ardnacrusha. The majority of eels observed were moving upstream and, with the exception of small numbers of silver eels, many of the downstream eel movements seemed to involve fish moving upstream that had failed to leave the fish lift. (McCarthy et al 2008)

A trap and truck system is used for upstream passage of elvers (young eels). The elver traps, which have been in operation at Ardnacrusha Dam since 1959, also capture small yellow eels. Since 1985, the Parteen Weir fish ladder has had a trap to catch ascending small yellow eels which are used for stocking lakes.

In the past, there have been attempts to use the boat locks for fish passage. These attempts proved impractical because of the still water and lack of attraction flow. However, when there are high velocities in the tailrace salmon still congregate downstream of the lock gates and it is possible some fish may pass via the boat locks. (Shannon Regional Fisheries Board 2010)

The Shannon Salmon Restoration Project Management Plan 2010 had several recommendations related to upstream passage, including:

- Examine the effectiveness of the fish lock at Ardnacrusha Dam and the fish ladder at Parteen Weir
- Investigate new methods of getting fish around the dam, such as spillways and rock ramps through a desk review of international best practices in the area of fish passage
- Characterize adult salmon movement through the Shannon system

Based on these recommendations it is clear that there currently is not sufficient knowledge of passage efficiency through the fish lock.

Downstream Passage

Depending on flow conditions in the River Shannon, the options for downstream migration vary. When the headrace canal is operational, the 33 foot wide navigation gate at the entrance is usually lifted and fish can migrate from the River Shannon to Ardnacrusha Dam, where they pass through trash screens and then through the turbines. They may also use the main river channel and pass via the small turbine or through the fish ladder at Parteen Weir. During higher flow events when more water than 10 m^3/s (353 cfs) is passed down the river channel (spillage occurs), the fish may pass through a set of three 59 foot wide undershot gates.

According to the Shannon Salmon Restoration Project Management Plan 2010:

> During the annual run, smolts congregated in large numbers in front of the dam wall at Ardnacrusha and failed to exit downstream. As a conservation measure, water was spilled through the boat lock and C. J. McGrath concluded that this provided a passage for a portion of the migration. The effectiveness of this method was never assessed, but it is likely that the delay prior to release of the smolts resulted in significant mortalities from stress and predation. In 1991 a smolt / generation protocol was initiated which arranged for generation to take place at night time as well as in daylight hours. This resulted in the cessation of the congregating of smolts above the dam, as they presumably passed through the turbines. (Shannon Regional Fisheries Board 2010)

The Kaplan turbine at Ardnacrusha is considered to be fish-friendly compared to the three older Francis turbines. In 2004, a study was done to determine the survival of hatchery-reared smolts passing through the Kaplan turbine. The study did not consider increased vulnerability to predation or physiological stress. Results showed that more than 90% safely passed the turbine while 4.3% of the smolts were visibly injured or suffered immediate mortalities. A previous study in 1991-1993 used coded-wire tagged smolts to estimate overall mortality caused by turbine passage. They estimated the mortality to be 8.5%. (Shannon Regional Fisheries Board 2010)

The Shannon Salmon Restoration Project Management Plan 2010 had several recommendations related to downstream passage, including:

- Assess such indirect effects as predation, disease and physiological stress of turbine passage of migrating smolts
- Assess entrainment on the Francis turbo-generators

- Examine current smolt passage mitigation protocols, determine if these are being observed and if there is a possibility for improvements
- Assess the effectiveness of the use of smolt traps and the transfer of smolts downstream

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Scotland

Tongland Hydroelectric Project

Location: River Dee, Scotland

Owner: Scottish Power

Dam Name: Tongland **Hydraulic Height:** 72 ft **Year Constructed:** 1935

Target Species: Atlantic salmon

Upstream Passage: Fish ladder (multiple types)

Downstream Passage: Turbines

Description

Tongland Dam (Tongland) located on the River Dee in Scotland, is part of the Galloway hydroelectric power scheme. It has a total generating capacity of 33 MW and an average net head of 105 ft. The primary portion of the dam is arch type and the eastern portion of the dam is gravity type. Tongland is the furthest downstream dam of a series of dams, so it is one of the most important in terms of fish passage. After water passes through the turbines, it flows to an estuary and into the Solway Firth.

Fish Passage History

During the design of the hydroelectric scheme it was noted that preserving the River Dee as a salmon fishing river was a very important issue. Physical models of the different fishways were built at University College, London, to help select the number of pools, size of pools, etc. Laboratory experiments were also done to determine the effect on smolts passing through the turbines. Observations of smolts as they passed from the surge shaft through the turbines showed that very few smolts were injured and it was decided not to install smolt screens at the intake. (Galloway Fisheries Trust and The Carnie Consultancy 2010)

The fish ladder was constructed during the time of dam construction. The ladder was completed in 1934. The original ladder design can be seen in Figure 204. In 1960, improvements to the fish ladder were made to convert the access between pools from orifices to overspill. In 1999, baffles were installed in the upper pools of the ladder to make it easier for salmon to pass. A new hatchery was funded in 2005.

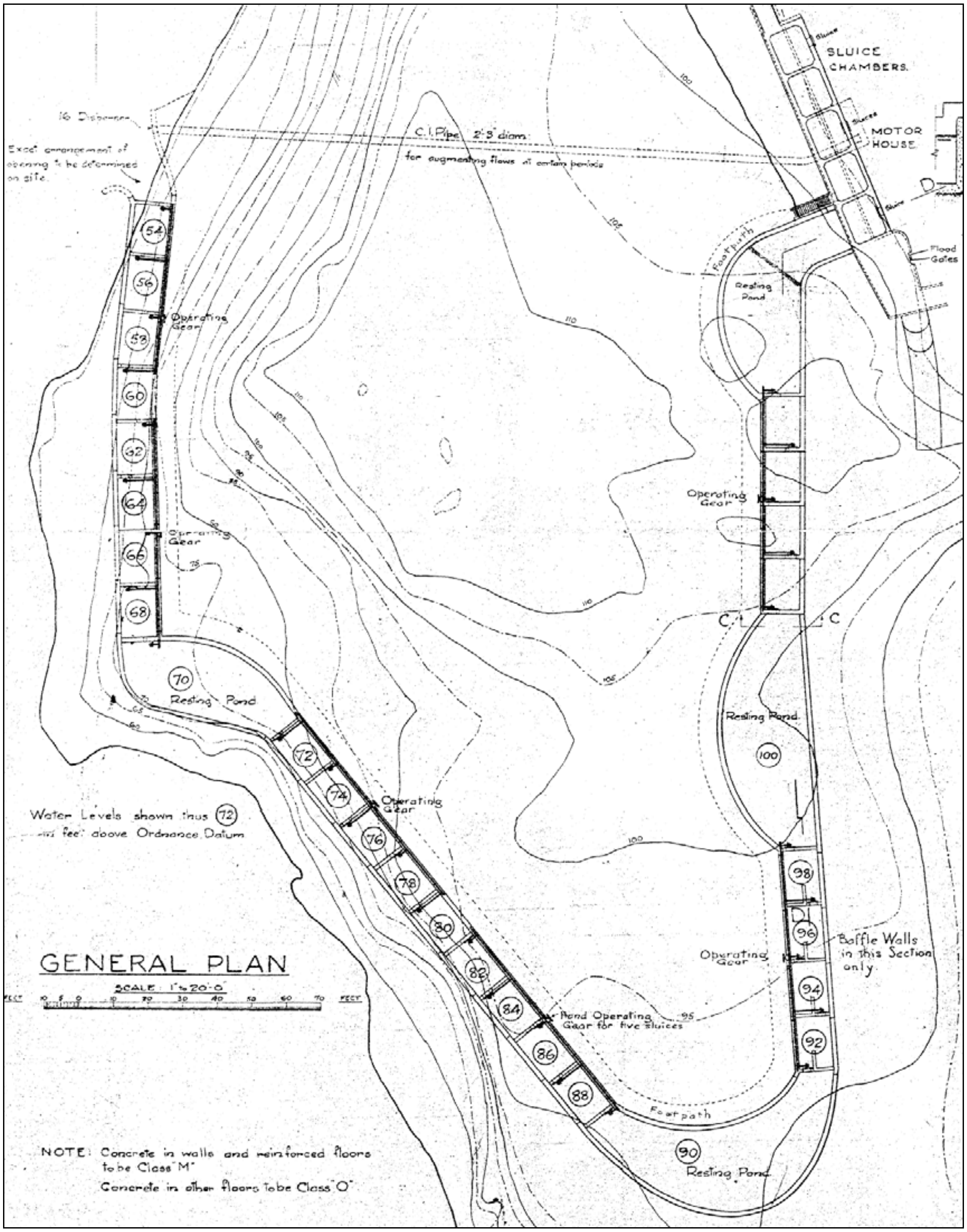

Figure 204. Tongland Dam Fish Ladder – Original Design (courtesy of Galloway Fisheries Trust)

Upstream Passage

The fish ladder configuration at Tongland originally consisted of 34 pools, with a total lift of approximately 69 feet (2 feet per pool). The upper 5 pools are constructed in the wall of the dam and were originally connected using submerged gates that are nominally 1.25 feet deep by 1.5 feet wide. The remaining lower pools were originally connected by orifices, but many were converted in 1960, to operate by free overflow over weirs between pools.

The current layout of the various sections of the fish ladder can be seen in Figure 205. In the original design, flow was controlled by sluice gates that could vary the area of each orifice. The only sections with the orifices still in use are sections 3 and 4, with the orifices fully open above the water level (Figures 206 and 207). In other sections, the orifices and their controls remain, but within sections 1 and 2, the sluice gates have been closed and notches were cut into the walls between chambers; therefore converting them to pool and over-fall structures (Figures 208 and 209). The notches do not extend to the bottom of the pools so fish must jump up each pool as they ascend. Additional changes to the original ladder include adding a weir to the center of resting pool 3. The connection between the lower and upper pool is through a submerged orifice leading into a Vaki fish counter tunnel (Figure 210). Near the upstream end of the ladder, section 5, originally comprised of a resting pool with two chambers, which now consists of four chambers with notches to create pool and over-fall structures but with the original orifices at both ends (Figure 211). The final, most upstream, section of the ladder continues through five chambers in the dam wall which use the original orifices and contain exit gates which operate on either the 1st, 3rd, or 5th chamber depending on the level of water behind the dam. Each of the five chambers also contain wooden baffles with submerged orifices (Figure 212). (Armstrong 11/1/2010, personal communication)

Historically, adult salmon had been known to have difficulties passing the upper five pools (within the dam wall). As described in an Ervine (University of Glasgow) et al paper, a small scale physical model study was done to investigate the problem. Velocity patterns, turbulence, head loss between pools, surging, and water surface levels were measured. The model results showed high inlet velocities in each pool and excessive turbulence. To see if the velocities could be reduced, the model was modified to have diagonal walls (baffles) with submerged orifices. Initially, just diagonal walls were thought to be sufficient but the problem with this configuration is that the weirs would operate in a drowned regime over much of their operation. So orifices were added to avoid this problem. The model results were good so field tests began in May 1998. The field results matched model results, with minimal swirl at each pool outlet. It also was observed that fish were no longer trapped at the resting pool just downstream of the 5 pools, and they ascended the ladder completely.

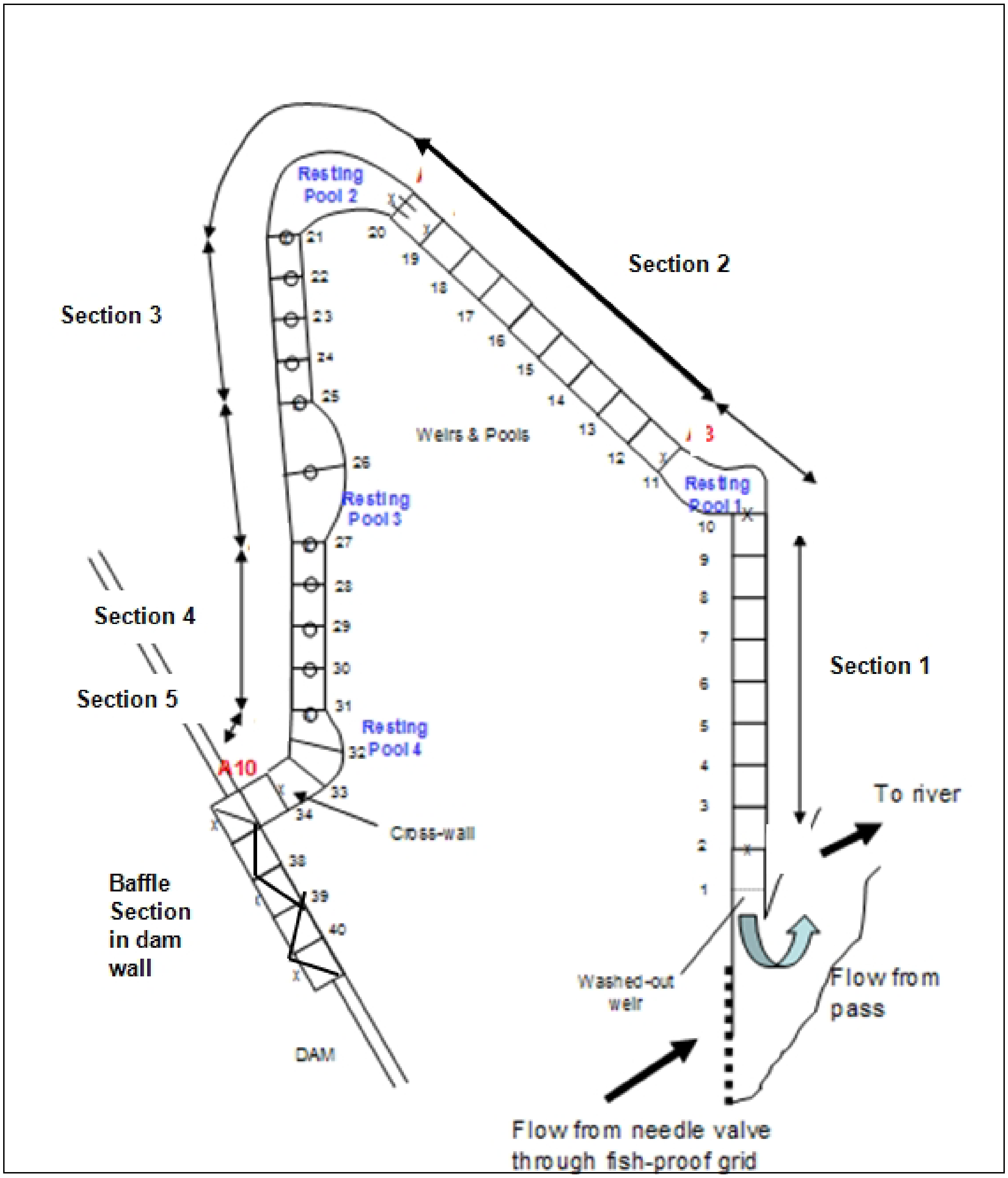

Figure 205. Fish Ladder Sections – Current Layout (Courtesy of Galloway Fisheries Trust)

Figure 206. Orifice section – downstream view (Courtesy of Galloway Fisheries Trust)

Figure 207. Orifice section – upstream view (Courtesy of Galloway Fisheries Trust)

Figure 208. Notches in Section 1 (Courtesy of Galloway Fisheries Trust)

Figure 209. Notch above resting pool 1 (Courtesy of Galloway Fisheries Trust)

Figure 210. Weir in resting pool 3 – with submerged orifice and fish counter tunnel (Courtesy of Galloway Fisheries Trust)

Figure 211. Section 5 of the fish ladder (Courtesy of Galloway Fisheries Trust)

Figure 212. Fish ladder baffle section (within the dam) (Courtesy of Galloway Fisheries Trust)

The 2010 Salmon Fishery Management Plan has a good description of flows through the fish ladder:

> Prior to April 2007, the pool-and-traverse fish pass [fishway] had a flow of 5 mgd (0.26 $m^3 s^{-1}$) [9 cfs] all year, with an additional compensation flow of 10 mgd (0.53 $m^3 s^{-1}$) [19 cfs] released from the dam during the months March to October inclusive, thus for the period when salmon might be expected to migrate upstream, the flow in the River Dee below the dam was 15 mgd (0.79 $m^3 s^{-1}$) [28 cfs]. Since April 2007 the total compensation flow below Tongland Dam has been increased to 20 mgd (1.05 $m^3 s^{-1}$) [37 cfs], 5 mgd (0.26 $m^3 s^{-1}$) [9 cfs] is released through the fish pass [fishway] and 15 mgd (0.79 $m^3 s^{-1}$) [28 cfs] from the compensation valve. Following discussions it was agreed that from 2007 the period of additional compensation flow will extend to the end of December so as to assist the upstream migration of late running salmon. (Galloway Fisheries Trust 2010)

A Logie 2100C resistivity counter was installed in the fishway at Tongland in 1962 to determine the number of Adult salmon passing. There were many concerns regarding the accuracy of the resistivity counter, so a Vaki Riverwatcher fish counter was purchased as a replacement and installed in 2007. The fish counter is located in resting pool 3, as discussed previously (see Figure 210).
From 2006 to 2008, a PIT tag study was done by Galloway Fisheries Trust, Dee District Salmon Fishery Board (DDSFB), and Marine Scotland Science, to identify any problems with the fish ladder. Fish were tagged downstream of the fish ladder in a fish trap adjacent to Tongland Power Station and PIT detectors were located throughout the fish ladder. Of the 44 fish that were tagged, 35% were recorded at the lowest PIT detector at the ladder. It was found that fish moved through the ladder exclusively during daylight hours. Data analysis also showed that salmon that entered the ladder

moved through it within two days. Many fish that were tagged were not recorded at the ladder, so further study needs to be done to determine the cause of this. (Galloway Fisheries Trust and The Carnie Consultancy 2010)

There are several actions listed in the 2010 Salmon Fishery Management Plan related to upstream passage. The actions include to:

- Determine if the ladder is a temperature barrier for spring run salmon by utilizing the fish trap and Vaki counter results.
- Investigate whether reducing fish ladder flow but maintaining compensating flows is possible. There is more energy dissipation and thus turbulence than expected in the ladder so reducing the ladder flow may make upstream migration easier.
- Install an eel ladder at the fishway to allow them to move upstream, or trap and manually move them upstream. Eels are an important predator of crayfish and therefore are beneficial to the upstream watershed.
- Investigate further increasing the combined fish ladder and compensation flow to at least 2.43 $m^{3/}s$ (46.18mgd) [86 cfs] which is the natural 95th percentile flow.

Downstream Passage

The primary means for downstream passage at Tongland is through the turbines.

While some smolts are known to safely pass through the tubines, the degree of mortality is not well known. There is an issue with smolts becoming trapped in the surge tower at Tongland where the primary escape is through the overspill. Kelts (adult salmon that have spawned) are known to have problems passing downstream of Tongland after spawning and many are found trapped in the reservoir. The fish counter has shown some kelts migrating downstream; however, there is an extremely low chance that they will survive to spawn again.

There are several actions listed in the 2010 Salmon Fishery Management Plan related to downstream passage. The actions include to:

- Determine the level of salmon smolt mortality caused by the turbines under different operation scenarios.
- Determine if operational changes can allow smolts to leave the surge tower instead of washing over the upper spillway flume.
- Determine if it is feasible to construct a bypass channel or fish trap near the turbine intake for kelts to pass downstream. This would also benefit smolt migration.

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Brazil

Itaipu Hydroelectric Project

Location: Parana River, on the border of Brazil and Paraguay

Owner: Itaipu Binacional

Dam Name: Itaipu **Hydraulic Height:** 394' **Year Constructed:** 1982

Target Species: various (non-salmonids)

Upstream Passage: Multiple-section fishway consisting of nature-like fishway, fish ladders, and artificial ponds

Downstream Passage: The fishway used for upstream passage is also used for downstream passage

Description

The Itaipu Hydroelectric Project (Itaipu) was completed in 1982. It is located on the Parana River, which is the fourth largest in the world in drainage area, the fifth longest, and the ninth largest in flow. The dam is located on the border between Brazil and Paraguay.

The power plant at Itaipu is the largest hydroelectric power plant in the world in terms of energy generation. The system supplies 16.4% of the energy consumed in Brazil and 71.3% of the energy in Paraguay. There are a total of 20 generator units that can produce up to 14,000 MW. (Itaipu Binacional 2010)

Fish Passage History

Prior to the construction of the dam, a natural fish barrier existed on the Parana River at Sete Quedas waterfalls. The waterfalls dropped roughly 262 feet over a distance of roughly 9 miles. The dam was constructed approximately 106 miles downstream of the waterfalls. The waterfalls were inundated when the reservoir filled and the formerly two distinct ichthyofaunistic provinces were partially connected; the dam became the new downstream barrier. There were no fish passage facilities at the dam from its construction until 2002, when the fishway, the Canal da Piracema (Canal) was completed. The construction of the fishway was somewhat controversial since it further connected the distinct downstream province with the upstream province. (Makrakis et al 2007)

Upstream Passage

The total length of the Canal is approximately 6.2 miles, making it the longest fishway of its type in the world. An elevation difference of 394 feet is overcome by the system. (Fiorini et al 2006)

From the opening of the Canal in December 2002 up to January 2010, there have been 135 species of fish found throughout the Canal; this includes about 40 species of long and medium migratory distance fish (Fernandez 2010).

The Canal has a mean depth of 11.5 feet where it leaves the reservoir and has a mean flow of 424 cfs. There are a total of eleven gates that are used to control water discharge throughout the Canal. The Canal is composed of several different sections including nature-like fishway, fish ladders, and artificial ponds.

An excerpt from a journal article by Makrakis et al (2007) in Neotropical Ichthyology, describes the different components of the system in further detail below. Please note that the capital letter codes in the text and map below were used to signify sampling locations. Figure 213 depicts a map of the Canal and displays the different sections that will be discussed. Figure 214 shows an aerial view of a section of the Canal.

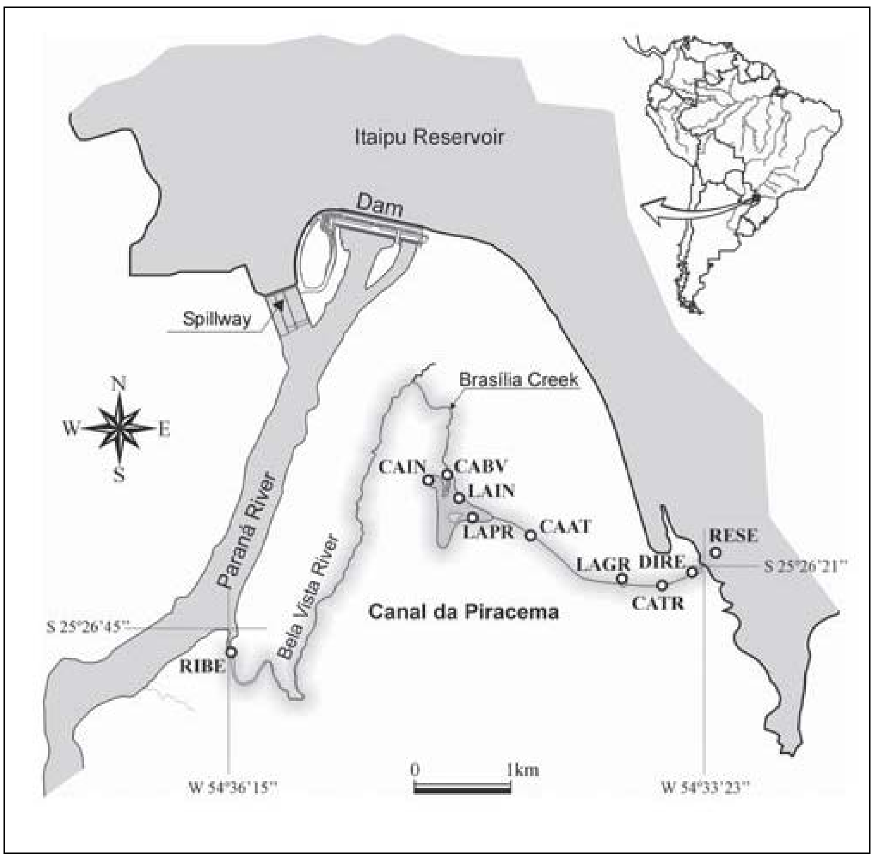

Figure 213. Map showing the Canal da Piracema (source: Makrakis et al 2007)

Figure 214. Aerial view of a section of the Canal da Piracema, including pond and fish ladders (Courtesy of Itaipu Binacional)

The first section of the Canal da Piracema from downstream to upstream is a nature-like fish pass [fishway], the Bela Vista River (RIBE), which flows into the Paraná River. This stream was widened to 4 – 6 m and deepened to 0.5 – 2.0 m. The total length of this stretch is approximately 6.7 km, with a 4.0% mean slope. Rocks were removed to eliminate the higher waterfalls in parts of this river. The Bela Vista River enters the Paraná River at an approximately 60º angle from the downstream direction, which apparently may decrease the attractiveness of the Canal da Piracema. In this area, the Paraná River is about 720 m wide, which varies depending on discharge. The mean discharge of the Paraná River is approximately 10,000 m3/s, and the water velocity is 2.0 m/s at the surface. The Brasília Creek runs for 800 m to the Bela Vista River. This stream was widened to 5 m and deepened to 0.5 –1.0 m. Its banks have a 4:1 slope (vertical: horizontal). The slope of Brasília Creek is 4.0%, and this section is the shallowest and the most turbulent.

The next section is a ladder, herein named CABV, constructed of reinforced concrete, 5 m wide with a 6.25% slope, which extends for about 150.5 m. It is rectangular in cross-section, 5.0 m wide and 2.5 m high, and it is provided with concrete barriers spaced every 4 m to reduce the water velocity. The concrete barriers have a 1 m opening, alternately on the right and left side of each barrier.

The central elements of the Canal da Piracema are two artificial ponds, a small lake (herein named LAIN, area of 1.2 ha and depth of 4 m) and a large lake (herein name LAPR; area of 14 ha and depth of 5 m), which are resting pools for fish. The banks are covered with soil, vegetation, and rocks of different sizes. The LAIN is drained by the

> fish ladder into the Brasília Creek, through a short section fitted with concrete deflectors. These two ponds are connected by a fish ladder (herein named CAIN), constructed of reinforced concrete and equipped with transverse barriers to control the water velocity. The ladder winds between the resting pools, and is 521 m long with a 1.5% slope.
>
> The next section is a fish ladder (herein named CAAT) stretching 1.6 km. This ladder has a trapezoidal cross-section, constructed in landfill, with a maximum width of 12 m and banks with a slope of 2:3. The bottom and sides of this ladder are covered with riprap, as in the first part. This section has a mean slope of 3.1% in the first stretch, 2.0% in the middle, and 0.8% in the final stretch. This ladder in turn opens into the LAPR. Another artificial pond (herein named LAGR) with 0.5 ha in area and a mean depth of 3.0 m is located after this ladder. Sides and bottom are covered with irregularly shaped riprap; it was also constructed as a fish resting pool. A fish ladder, herein named CATR, is above this pond which extends for 2.4 km, with the first 0.73 km of the ladder excavated in a trench. This ladder is trapezoidal in cross-section, 8 m wide at the bottom, with a 2:3 slope of the embankment, excavated in alluvial basalt. Its bottom and sides are covered up to the water level with irregularly shaped riprap, as well as concrete deflectors, spaced to reduce the flow velocity. These deflectors are 0.6 m high, with lateral openings of 1.0 m, located on alternate sides in relation to the banks. The slope is 5.0% on average in the beginning stretch, 0.7% in the middle, and 5.0% in the final stretch.
>
> The last section is the area of water intake, herein named DIRE. This area is formed by concrete water-intake structures and the stabilization pond. The water intake and the stabilization pond have a mean depth of 3.3 m and an area of 0.4 ha. The DIRE is composed of three floodgates, 2.0 m in height, that maintain the maximum level of the stabilization pond 0.45 m below the surface level of Itaipu Reservoir, to limit the velocities in the intake sluices to less than 3.0 m/s along the Canal. (Makrakis et al 2007)

The Makrakis et al (2007) journal article reported on the results of a passage study that evaluated the ichthyofauna present and the abundance and distribution in the Canal. Results of the study showed that the number of species found in the uppermost reach of the Canal decreased significantly compared to the lowest reach. This suggests that many species are not able to navigate all reaches of the fishway system. One difficulty in implementing the study was that multiple sampling methods were required due to the vastly different environmental conditions throughout the Canal, which made it more difficult to compare reaches. The journal article suggests that the greatest obstacles for fish are the stretches of the Bela Vista River and the following fish ladder (CABV), which links the resting pool (LAIN) to the Bela Vista River, because of its hydrodynamic characteristics, such as water velocity, shallow rock-free areas, and high turbulence (Makrakis et al 2007). The article also states that the hydrological characteristics of the Canal need to be evaluated and provided to the engineering sector so they can adjust the hydraulics to improve fish passage.

The article also noted that at least one species of the distinct downstream province had moved upstream (above the historical natural barrier) and multiple species had been recorded in the downstream distinct province that were originally from the upper province. Continued monitoring is needed to evaluate possible introductions due to the fishway system.

Downstream Passage

The fishway system discussed for upstream passage is also used as the primary means for downstream passage. At least some of the species sampled in the Makrakis et al study were actually fish migrating downstream.

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Dam Removal

United States — Washington

Elwha and Glines Canyon Dams

Location: Elwha and Glines Canyon Dams are located on the Elwha River in Olympic National Park of Washington State. Elwha Dam is located approximately 5 miles upstream from the mouth of the river on the Juan de Fuca Strait. Glines Canyon Dam is located approximately 8 miles upstream of Elwha Dam.

Owner: The US Bureau of Reclamation (USBR) owns the dams. The USBR and the National Park Service is currently operating the Dams, and will do so until their removal.

Dam Name: Elwha	**Hydraulic Height:** 98’	**Year Constructed:**	1914
Dam Name: Glines Canyon	**Hydraulic Height:** 200’	**Year Constructed:**	1927

Year Dams Removed: Removal started in September 2011.

Dams Removal Reason: The Elwha River was once renowned for an abundance and diversity of anadromous salmonids. Approximately 83% of the river system lies within Olympic National Park and is in pristine condition (Wunderlich et al 1994). Since the beginning of construction of Elwha Dam in 1911, the Elwha and Glines Canyon dams have blocked anadromous fish passage to more than 70 miles of the Elwha River and its tributaries, thus limiting anadromous salmonid production to the lower 4.9 miles of the river. The result is that all 10 native Elwha River anadromous fish runs (spring, summer, and fall-run Chinook, coho, pink, chum, and sockeye salmon, winter and summer runs of steelhead, sea-run cutthroat trout, and native char) have been severely reduced (USDI 1994). In addition, natural river processes, such as sediment transport, have been disrupted and the dams increase water temperatures in the river in late summer and fall (Wunderlich et al 1994).

Project Description
The Elwha River watershed (Figure 215) is 321 square miles in size, of which 267 square miles (83%) are within the boundary of Olympic National Park. The river has a north-south orientation, flowing north for about 45 miles to enter the Strait of Juan de Fuca near Port Angeles, Washington. Winter

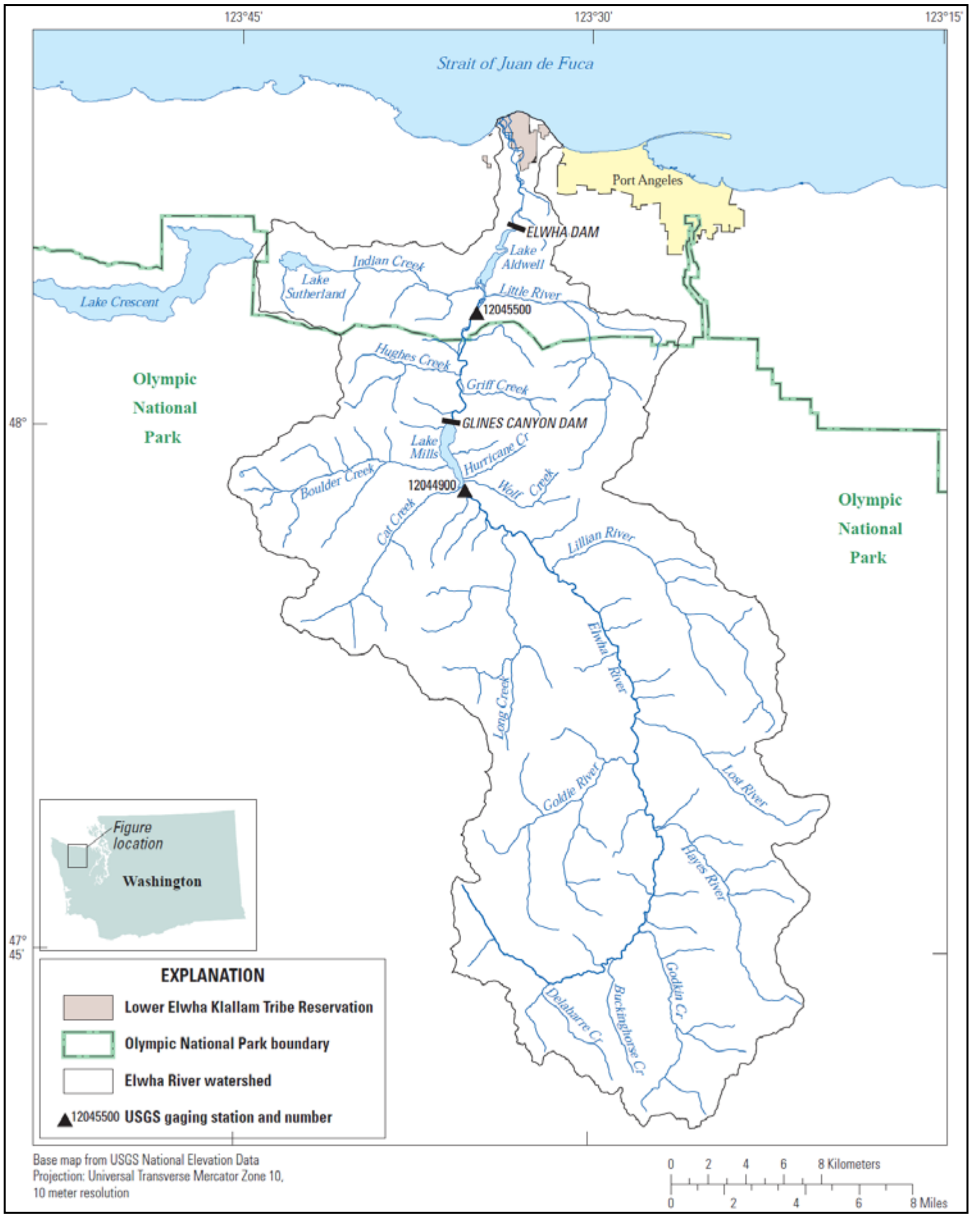

Figure 215: Elwha River Watershed (Courtesy of the USGS)

flows average approximately 2,000 cfs, while summer flows average roughly 600 cfs. Peak flow events have surpassed 40,000 cfs, while summer flows may be as low as 200 cfs (Ward et al 2008).

Olympic Power and Development Company completed construction of the Elwha Dam in 1912 (Figure 216). The 105-foot-high (98-foot hydraulic height), 450-foot-long concrete gravity dam, located 4.9 miles from the Strait of Juan de Fuca, created Lake Aldwell, which was about 2.5 miles long and had a capacity of 8,100 acre-feet. Glines Canyon Dam (Figure 217) was a 210-foot-high (200-foot hydraulic height) single arch concrete dam located 8.5 miles upstream of Elwha Dam, and was completed in 1927 by Northwestern Power and Light Company. Glines Canyon Dam created Lake Mills, which was 2 enerat- ed ov

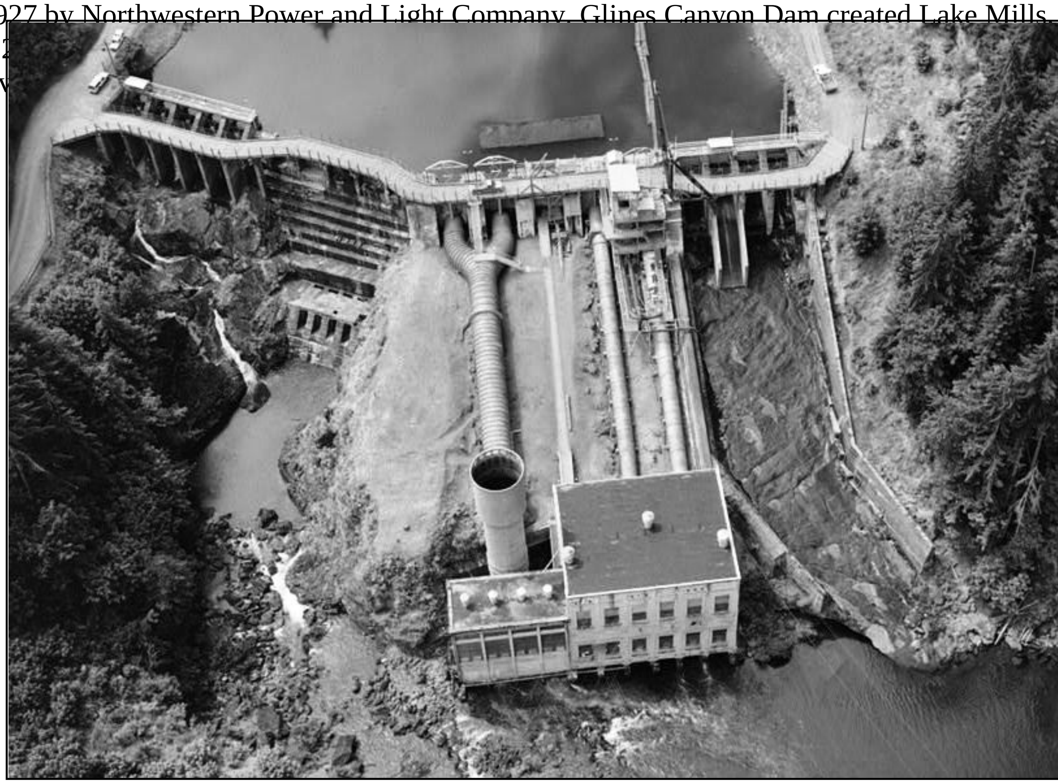

Figure 216: Elwha Dam - 1995 (Photo by Jet Lowe, Library of Congress)

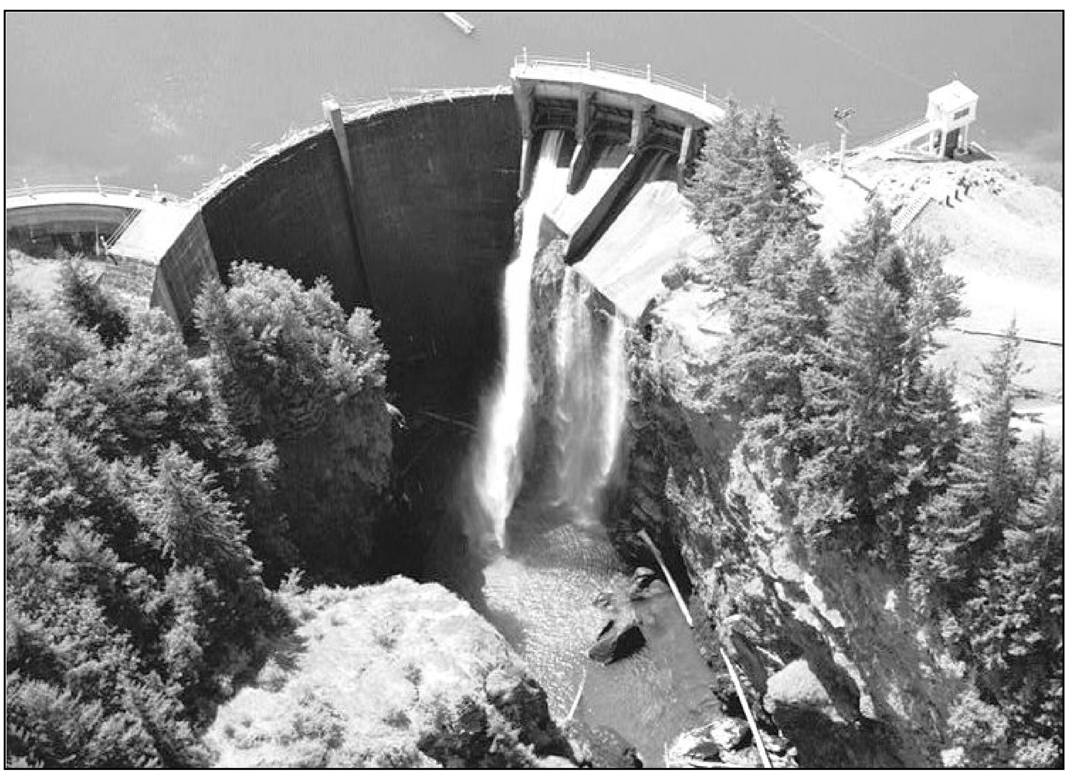

Figure 217: Glines Canyon Dam - 1995 (Photo by Jet Lowe, Library of Congress)

Fish Passage History

Neither dam was equipped with fish passage facilities, even though Washington State law required it. The State Fish Commissioner allowed the dam builders to build a hatchery instead. Because Elwha Dam had no fish passage facilities, Glines Canyon Dam was not required to have them (Wunderlich et al 1994).

From Pess et al 2008:

> The Elwha River dams have blocked upstream migration of salmonids to over 90% of the watershed for over 90 years and have disrupted the downstream movement of habitat forming inputs such as sediment and wood. Together this has resulted in a loss of spawning and rearing habitat upstream of the dams, as well as reduced spawning and rearing habitat below the dams due to habitat degradation. The result of this and other impacts has led to a 90% reduction of salmonid population size, a loss of specific upstream stocks, and a shift in species composition.

Dam Removal

Restoration of the Elwha River was mandated by Congress in 1992 by The Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495). The goal of the Act was the "full restoration of the Elwha River ecosystem and native anadromous fisheries". The Act authorized the Secretary of the Interior to acquire the Elwha and Glines Canyon projects and remove the dams if it was determined that removal was the only way to meet this goal. The Secretary developed a report documenting the conclusion of the investigations and provided it to the Congress in 1994. In the report, four alternatives were examined: providing fish passage at both dams, removing both dams, removing Glines Canyon dam and providing fish passage at Elwha Dam, and removing Elwha Dam and providing fish passage at Glines Canyon Dam. These alternatives were compared to the no action alternative, and it was concluded that removal of the dams was feasible and the only alternative that provided “full restoration” (USDI 1994).

In June 1995, the Final Programmatic Environmental Impact Statement (EIS) was released, which concluded that both dams need to be removed to achieve full restoration of the Elwha River ecosystem and native anadromous fisheries. In February 1996, the Record of Decision was signed in favor of dam removal (NPS 2012e). One of the main issues with removing the dams was what to do with all the sediment trapped in the reservoirs. In 1994, there was an estimated 17 million cubic yards of sediment in the reservoirs (USDI 1995). In November 1996, the Final Implementation EIS was released, which concluded that the sediment within the two reservoirs should be allowed to erode naturally following dam removal, and that plans for fish restoration and revegetation, as well as other actions, should be implemented (NPS 2012e).

To update the volume of sediment stored in the reservoirs, surveys by the USBR in 2010 found that they contained 24.3 million cubic yards of sediment, with 20.4 million cubic yards being contained in Lake Mills (Bountry et al 2011). That amount of sediment is enough to fill a football field to the height of 11 Empire State Buildings. During and following dam removal, an estimated 9–10 million cubic yards of sediment will be transported by fluvial processes from the former reservoirs. It is estimated that most of the transported sediment will be fine grained silt, clay, and sand and the rest will be coarse-grained cobbles and gravels. The rate of transport will be dictated by the rate of dam removal, combined with the magnitude, frequency, and timing of storm events (Duda et al 2011).

In early 2000, the U.S. Department of the Interior purchased the dams in preparation for their removal. The United States Bureau of Reclamation began operating the hydroelectric projects shortly after the purchase (USBR 2012).

In 2008, the National Marine Fisheries Service and supporting agencies created the Elwha River Fish Restoration Plan (Ward et al 2008), which included: fish stock restoration descriptions, population recovery objectives, habitat restoration methods, and monitoring and adaptive management needs. The plan stated that the preservation of existing populations during dam removal was a key element of the restoration strategy, because it was thought that the release of the turbid water will be fatal to fish. To ensure that enough fish survived the deconstruction process, hatcheries were used. Also, special “fish window” periods were included in the dam removal schedule, stopping deconstruction and slowing the release of sediment to allow for migration, spawning, and collection of broodstock. Finally, monitoring would be done to ensure the restoration goals were being achieved and to determine appropriate adaptive management actions.

The Elwha River Ecosystem and Fisheries Restoration Act of 1992 states that water quality on the Elwha River must be protected before dam deconstruction will commence. Two water treatment plants were completed in early 2010 and were necessary projects to be completed before dam removal could commence. These facilities were constructed to protect the City of Port Angeles' municipal and industrial water supplies before, during and after removal of the two Elwha River dams. They also provide water for the Washington Department of Fish and Wildlife's fish rearing channel and the Lower Elwha Klallam Tribe's fish hatchery. Also constructed were a new surface water diversion and intake structure, and improvements to a road and area flood protection. Construction of the facilities cost $79 million, of which the Port Angeles Water Treatment Plant cost $27.6 million. Both water treatment plants protect water users from the high turbidity that occurred during removal of the dams (NPS 2012f).

The removal of Elwha Dam began on June 1, 2011, following the closure of the powerhouse. The reservoir's water level was lowered by approximately 15 feet using the dam's water intakes and spillways. As water was routed through the spillway on the left side of the dam (looking downstream), the gates on the right side of the dam were removed and a temporary diversion channel was excavated (Figure 218).

Water was then routed through the temporary channel and a lower temporary channel was excavated through the spillway on the left side to allow the reservoir to be drained further (Figure 219). As this channel was excavated the central portion of the dam was removed. The outflow was then switched to the left side temporary channel and work began on lowering the concrete on the right side of the dam and removing the penstocks and powerhouse (Figure 220). The flow of water was switched to the right side channel and back to the left a couple times to excavate the channels further. On January 27, 2012, water was switched to the left side channel for the final time and the right side channel was excavated to its original bed elevation (Figures 221). On March 16, 2012, the river flowed through its original channel for the first time in over 100 years at the dam site (Figure 222). The temporary channel on the left side was filled in and the contouring of the former dam site was completed as of July 2012 (Figure 223) (NPS 2012a, NPS 2012c).

Figure 218: Elwha Dam - September 22, 2011 (Courtesy of the NPS)

Figure 219: Elwha Dam – October 1, 2011 (Courtesy of the NPS)

Figure 220: Elwha Dam – November 17, 2011 (Courtesy of the NPS)

Figure 221: Elwha Dam – February 7, 2012 (Courtesy of the NPS)

Figure 222: Elwha Dam – March 16, 2012 (Courtesy of the NPS)

Figure 223: Elwha Dam Site after Removal - July 31, 2012 (Courtesy of the NPS)

Removal of Glines Canyon Dam began with the lowering of Lake Mills to the bottom of the spillway gates. On September 15, 2011, barge-mounted hydraulic hammers began removing the first 17 feet of the dam down to the waterline (Figure 224). A large part of the dam was removed using a notching process. The process used the barge-mounted hydraulic hammers to create notches in the dam large enough to drain the reservoir but small enough to not allow the barge to pass (Figures 225 and 226). This process continued until mid-April 2012 (Figure 227). Since that time, lowering of the dam has been accomplished by explosives. During required deconstruction stoppages to allow sediment loads to decrease downstream, the gatehouse, surge tower, intake tower, powerhouse, and above water sections of the dam have been removed. As of September 17, 2012 the dam has been lowered approximately 125 feet, with about 85 feet remaining (Figure 228). The rest of the dam will be removed by explosives, with an expected completion date of summer 2013 (NPS 2012a, NPS 2012b, NPS 2012c). Figure 229 shows the partially drained Lake Mills as of September 2, 2012 and figure 230 shows the dam from the former reservoir bed on November 6, 2012. The contract for the removal of both dams is $26.9 million dollars and the total cost of the Elwha River restoration is expected to be $325 million dollars. The restoration cost includes the purchase of the dams and power plants, construction of two water treatment plants and other facilities to protect water users, a fish hatchery, a greenhouse to propagate native plants for revegetation, and construction of flood protection facilities (NPS 2012d).

Figure 224: Glines Canyon Dam - September 23, 2011 (Courtesy of the NPS)

Figure 225: Glines Canyon Dam - October 25, 2011 (Courtesy of the NPS)

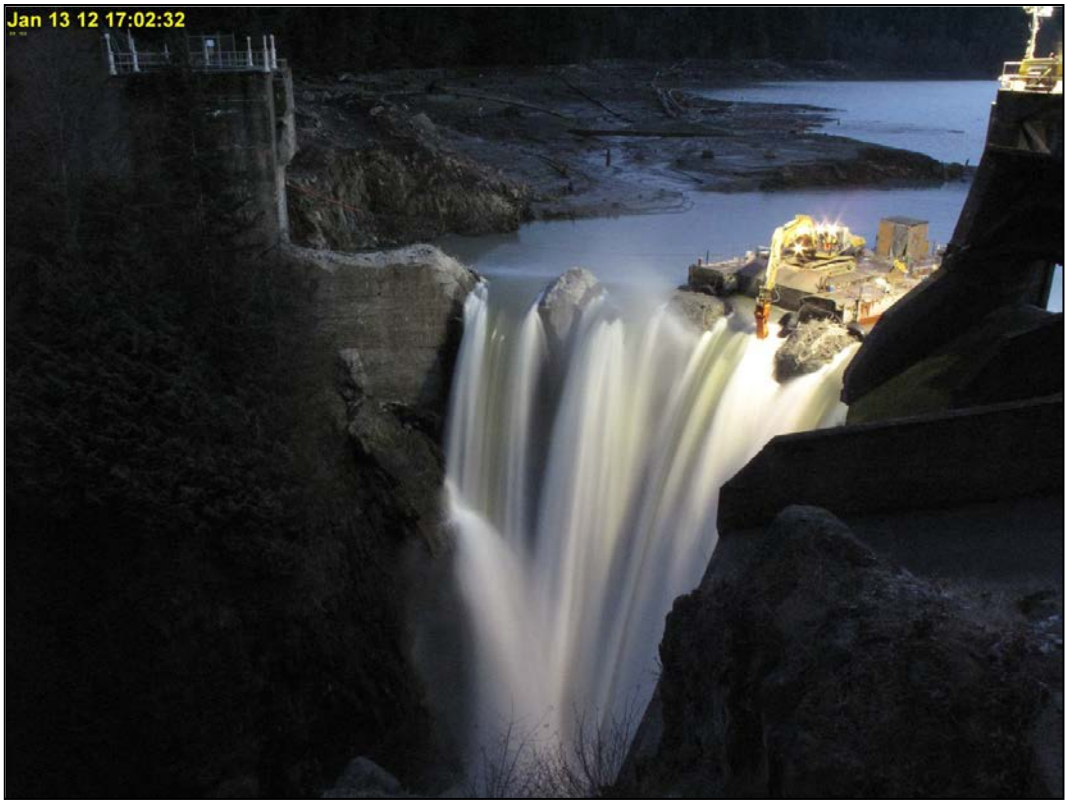

Figure 226: Glines Canyon Dam – January 13, 2012 (Courtesy of the NPS)

Figure 227: Glines Canyon Dam – April 15, 2012 (Courtesy of the NPS)

Figure 228: Glines Canyon Dam – September 17, 2012 (Courtesy of the NPS)

Figure 229: Lake Mills - September 2, 2012 (Courtesy of Tom Roorda, Roorda Aerial)

Figure 230: Glines Canyon Dam from Upstream - November 6, 2012 (Courtesy of Brian Cluer, NMFS)

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Condit Dam

Location: Condit Hydroelectric Project is located in south central Washington State on the White Salmon River approximately 3.3 miles upstream from its confluence with the Columbia River at Hood River, Oregon (Figure 231).

Owner: PacifiCorp

Dam Name: Condit Dam **Structural Height:** 125' **Year Constructed:** 1913

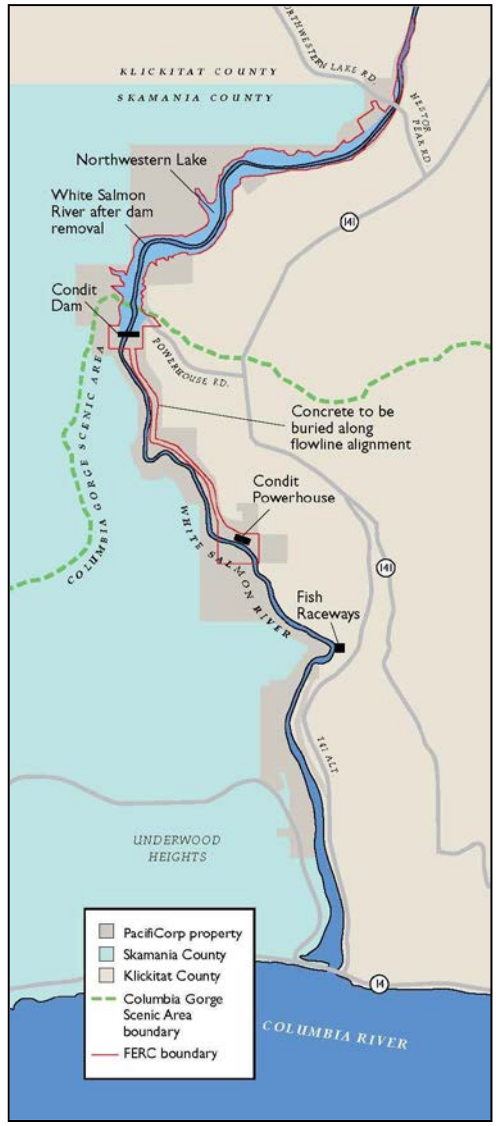

Figure 231: Map of the Lower White Salmon River (Courtesy of PacifiCorp)

Year Dam Removed: Dam removal began in July 2011 and was completed in October 2012.

Dam Removal Reason: Federal Energy Regulatory Committee conditions for license renewal, including construction of fish ladders and higher instream flows, would reduce Condit's overall energy production and render the Project uneconomical to operate.

Project Description

Northwestern Electric Company completed construction of Condit Dam in 1913. Originally built to power a paper mill in Camas, WA, Condit dam later generated electricity for local metropolitan areas in Oregon and Washington. The concrete gravity dam was 125 feet high and 471 feet long (Figure 232). At the dam, water was diverted into a 5,100-foot-long, 13.5-foot-diameter wood stave pipeline which fed two 9-foot-diameter, 650-foot-long penstocks. The powerhouse contained two horizontal Francis turbines with a combined generating capacity of 14.7 megawatts (NMFS 2006). Northwestern Lake, a 1.7-mile-long, 1,300-acre-foot reservoir created by the dam (NMFS 2006), contained approximately 2.3 million cubic yards of captured sediment (Inter-Fluve et al 2011).

A fish ladder was included when the dam was built, but washed out twice during floods during the dam's early years. The original wooden ladder was destroyed in 1914 and was immediately rebuilt. It washed out in 1918, and the Northwestern Electric Company and Washington State Fish Commission agreed not to rebuild it. Instead, Northwestern Electric Company would contribute to the construction of a fish hatchery on the lower Columbia River as mitigation. In 1925, a third attempt at fish passage at the dam was tried by the John H. Cobb, Director of the University of Washington's College of Fisheries, using an experimental fish elevator. The experiment was complicated by shortage of water in the river below the dam, since most of the water was run through the flow line to the powerhouse. Researchers had to transport the test salmon in the rumble seats of their cars to the base of the elevator. Although many of the fish died in the process, the experiment proved conclusively that if the fish could be induced to enter the elevator, they could be lifted to almost any height desired. The elevator was not used after the experiment ended (EDAW 2002).

Pacific Power and Light acquired the project through a merger with Northwestern Electric Company in 1947. Pacific Power and Light was renamed PacifiCorp in 1984, and in 1991 filed an application for a new license with FERC. In 1996, FERC issued a final Environmental Impact Statement, which dictated conditions for the continued operation of Condit Dam. Some of the conditions included installation of fish passage facilities, at an estimated cost of $30 million dollars, and higher in-stream flows. Under these conditions, continuing the operation of Condit Dam would have been uneconomical for PacifiCorp. PacifiCorp sought less expensive options, but none of these were adopted and they entered into a settlement process, where it was decided that they would remove Condit Dam (EDAW 2002, PacifiCorp 2011).

Figure 232: Condit Dam (Courtesy of PacifiCorp)

Figure 233: Breach Tunnel (Courtesy of Narrative Lab)

To begin dam removal, in early August 2011 the reservoir was lowered by approximately 10 feet and blasting of a 13-foot by 18-foot tunnel was begun at the base of the dam (Figure 233). The blasting work continued until the tunnel was approximately 15 feet from the upstream side of the dam. During the same time period, workers dredged the sediment immediately upstream of the dam (Time lapse website). No wholesale sediment removal or stabilization was completed, as the river would be allowed to transport the sediment from the former reservoir area. Pre-project modeling estimated that most of the reservoir sediment would be transported as the reservoir drained (Inter-Fluve et al 2011). On October 26, 2011, the final 15 feet of concrete was blasted and the lake spectacularly drained (Figures 234 and 235) in less than 2 hours through the tunnel (Maser and Stampfli 2012).

Figure 234: The Breaching of Condit Dam (Courtesy of Andy Maser and Steve Stampfli)

Over the next year, excavators with hydraulic hammers chipped away at the dam from the top down, breaking it down into manageable chunks for loading and hauling (Figures 236 - 241). Once the excavation reached the lower portion of the dam, controlled blasting was used to fracture the concrete into large chunks that were lifted out with a crane's clamshell bucket (Maser and Stampfli 2012).

In addition to the dam, the cofferdam, crib dam, and diversion flume, which aided in the original construction, were removed, as well as the flowline, surge tank, power lines, tailrace wall, and operator's building. Most of the penstocks were removed, with a concrete plug installed in the portion that is below ground level. The powerhouse was left intact (Mead and Hunt et al 2011).

The concrete removed from the dam site was placed along the path of the former flowline and then covered with 18" of soil and planted with native vegetation (PacifiCorp 2012b). The last pieces of the dam were removed on September 2012, and by the end of October 2012, the dam removal project was

Figure 235: Northwestern Reservoir and Condit Dam after the breach (Courtesy of Andy Maser and Steve Stampfli)

completed with the removal of a large logjam near the removal site. Figure 712 shows a before and after view of the dam. PacifiCorp also stabilized the banks upstream of the dam site, revegetated the former reservoir with native vegetation, and restored wetlands. Approximately 30,000 cubic yards of material were removed during the project (PacifiCorp 2012a) and the project cost an estimated $37 million dollars (Florip 2012).

Removal of the dam allows access to roughly 33 miles of spawning and rearing habitat for steelhead and 14 miles of spawning and rearing habitat for Chinook salmon (NMFS 2006). Estimates of potential adult run sizes in the White Salmon River post dam removal are 700 steelhead, 4,000 spring-run and 1,100 fall-run Chinook salmon, and 2,000 coho salmon (whitesalmonriver.org 2012).

Figure 236: Condit Dam Removal, February 2012 (Courtesy of Andy Maser and Steve Stampfli)


Figure 237: Condit Dam Removal, April 2012 (Courtesy of Andy Maser and Steve Stampfli)

Figure 238: Condit Dam Removal, May 2012 (Courtesy of Andy Maser and Steve Stampfli)

Figure 239: Condit Dam Removal, July 2012 (Courtesy of Andy Maser and Steve Stampfli)

Figure 240: Condit Dam Removal, July 2012 (Courtesy of Andy Maser and Steve Stampfli)

Figure 241: Condit Dam Removal, August 2012 (Courtesy of Andy Maser and Steve Stampfli)

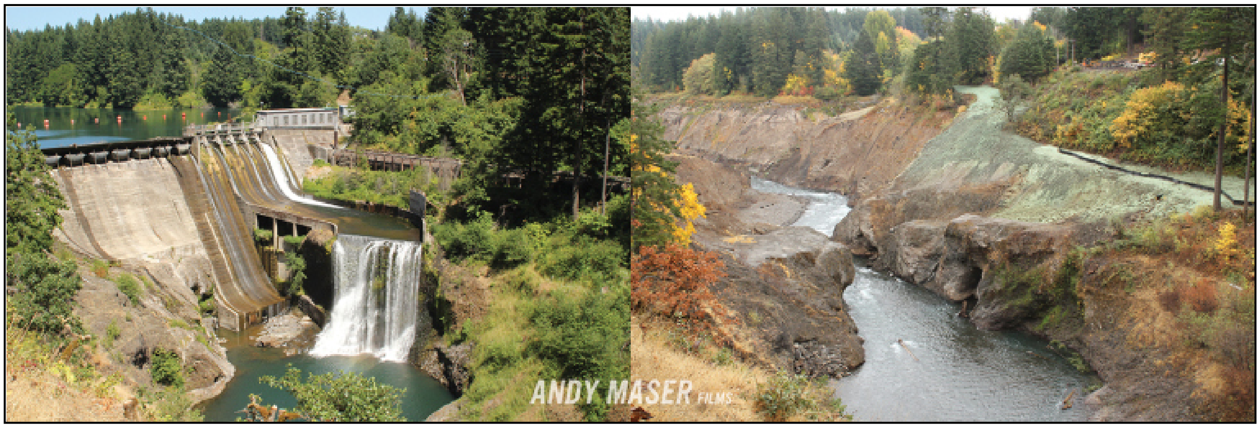

Figure 242: Before and After Photos of the Condit Dam Removal (Courtesy of Andy Maser and Steve Stampfli)

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United States — Oregon

Marmot Dam and Little Sandy Dam

Text to come.

United States — California

San Clemente Dam

Text to come.

Conclusions

There are numerous reasons why fish passage at large dams should be investigated in California. Senate Bill 2X No. 1 requires DWR to evaluate ways to integrate and reoperate flood protection and water systems under climate change scenarios and provide four benefits, one being to protect and restore ecosystems and wildlife habitat. The California Water Plan Update 2009 recommends that the State manage its water resources with ecosystem health and water supply reliability and quality as equal goals, and stated that reoperation of the water management systems can provide benefits in a changing climate. The NMFS Central Valley salmonid recovery plan recommends that the state develop alternative water operations and conveyance systems that improve conditions for Central Valley salmonids. California's Climate Change Adaptation Strategies call for the establishment of a System Reoperation Task Force to quantify the potential costs, benefits and impacts of system reoperation for fish passage, cold-water management for fisheries, and other ecosystem needs.

This paper's research is particularly relevant because climate change may adversely impact salmonid species, potentially reducing Sierra snowpack and eliminating summer holding habitat for spring-run Chinook salmon. Therefore, many researchers and agencies have recognized the need to evaluate opportunities to provide Central Valley salmonid species access to currently inaccessible habitat. In addition, providing fish passage to areas upstream of reservoirs could eliminate or reduce the need for cold water releases and give water managers additional flexibility in meeting downstream water supply and flood protection needs. NMFS has recommended that the State and its partners also evaluate opportunities for fish passage at many Central Valley dams as part of a suite of actions that must be taken to return winter-run Chinook salmon, spring-run Chinook salmon, and steelhead to viable status in the Central Valley.

On the West Coast, the single biggest cause of the decline of salmonid populations has been the construction of massive dams and diversions on all major rivers. In the Sacramento-San Joaquin system, dams have denied Chinook salmon access to more than half of the stream reaches they once used and to more than 80 percent of their historical holding and spawning habitat. Many populations have declined to the extent that they are listed as threatened, endangered, or a species of concern under the federal Endangered Species Act and California Endangered Species Act. Approximately 47% of California's salmonids are recognized as threatened, endangered, or extinct by state and federal governments.

In addition to blocking access to upstream habitat, dams block or delay fish migration, alter the river's natural exchange of sediment and organic material, degrade water quality and downstream habitat, and can kill or injure downstream migrants.

USACE's National Inventory of Dams database identifies over 1490 dams within California. Approximately 370 are 68 feet or higher. Several of these large California dams have been identified by NMFS as needing fish passage. To pass fish at dams and other instream structures, many types of technologies are used. Some of these provide volitional passage, such as fishways for upstream migrants and fish bypasses for downstream migrants. Non-volitional technologies include lifts, locks, and collection and transport. In California, all of the large dams, such as Shasta and Oroville, were constructed without upstream or downstream fish passage. In addition, since the dams at major reservoirs that ring the Central Valley did not provide passage, many of the hydropower facilities located at higher elevations were not provided with fish passage either. At smaller dams in California, upstream passage is provided almost exclusively through the use of fish ladders.

The case studies indicate that fish passage is provided at many large dams throughout the world. In the Northwest United States, many large dams have fish passage and many more will follow in the next few years. Fish passage is provided at the lower nine Columbia River Dams and the four Lower Snake River Dams, with hydraulic heights ranging from 40 to 105 feet. At the higher flood control, water storage dams in the Northwest, not all the large dams have fish passage, but many do or will in the near future.

In Washington State, 27 dams have hydraulic heads greater than 150 feet. Of these, 4 include Grand Coulee Dam (no fish passage mainly due to its 151 mile long reservoir upstream) and those under the influence of Grand Coulee Dam. Almost all of the others are multi-purpose dams, used for flood control, water storage, power generation, and recreation, amongst other things. Of these remaining 23 dams, 8 are at or above a historical natural barrier to fish passage, leaving 15 dams where fish passage could be a viable option. Of these, 8 dams currently have fish passage, including 277-foot Lower Baker Dam and 304-foot Upper Baker Dam on the Baker River and 230-foot Mayfield Dam and 529-foot Mossyrock Dam on the Cowlitz River. Of the remaining 7 dams, 5 dams have fish passage projects in design and 1 is scheduled for removal by 2013, leaving only 1 dam without an active fish passage project. Collection and transport is the only method used (or proposed to be used for those in design) for upstream passage at these large dams. Downstream passage is accomplished by fish bypass or collection and transport facilities.

In Oregon, fewer large multi-purpose dams have fish passage. The Pelton-Round Butte Project (with 204-foot Pelton Dam and 425-foot Round Butte Dam) on the Deschutes River and the North Fork Project (145-foot North Fork Dam, 56-foot Faraday Dam, and 70-foot River Mill Dam) on the Clackamas River, are the only projects with constructed facilities for both upstream and downstream passage. Of the eight dams in the Willamette River watershed with hydraulic heights greater than 150 feet, only 467-foot Cougar Dam on the South Fork McKenzie River and 181-foot Fall Creek Dam have fish passage. Both dams have a collection and transport operation for upstream passage but no downstream passage facilities. A downstream passage facility for Cougar Dam is currently in the planning stages and should be operational in the next couple of years. Through the NMFS Biological Opinion for the Willamette Projects, upstream fish passage will be implemented in the next few years for those dams blocking access to the upper reaches of the watershed. Downstream passage will be implemented more slowly, as Cougar Dam's downstream facility will be the test case for the watershed.

As the case studies show, fish passage can be implemented at large dams. In the Pacific Northwest, the technologies used for passing fish at large flood control, water storage dams are fairly new and have only been implemented in the last few years, but early indications look good as to the benefits of providing passage. However, only time will tell what the magnitude of the impact on anadromous fish species will be.

Appendix A. Full Text of California Senate Bill 2 X No 1

SB 2X No. 1 states:

(a) Water is vital to the economy, environment, and overall well-being of the state.

(b) California faces increasing challenges in managing its water supply due to climate change, uncertainty regarding the availability of water from the Sacramento-San Joaquin Delta and other sources, an increasing state population, limitations on public funds, and other factors.

(c) California must adopt a new, updated, and comprehensive set of water planning, design, and implementation policies that reflect these realities to protect its water supply future.

(d) In the past, state laws, funding schemes, and administrative actions have treated the planning, construction, and operation of water supply, groundwater, and flood control systems as separate and distinct activities, thereby reducing efficiency and water supply reliability.

(e) California has not taken full advantage of the cost savings, the environmental benefits, or the expediency of more efficient operations and usage of existing water supply, storage, and flood protection facilities.

(f) It is the policy of the state to more effectively integrate its flood protection systems with its water supply and conveyance systems in order to conserve limited public dollars, increase the available water supply, improve water quality, increase wildlife and ecosystem protections, protect public health and safety, and address the effects of climate change.

(g) The purpose of this division is to require the integration of flood protection and water systems to achieve multiple public benefits, including all of the following:

(1) Increasing water supply reliability in the least costly, most efficient, and most reliable manner to meet current and future state needs.

(2) Increasing use of water use efficiency and water conservation measures to increase and extend existing water supplies.

(3) Reducing energy consumption associated with water transport, thereby reducing state greenhouse gas emissions.

(4) Improving water management to protect and restore ecosystems and wildlife habitat.

83001. In order to provide the least costly, most efficient, and reliable water supply to a growing state, it is the intent of the Legislature that the department accomplish the following objectives: Integrate state flood protection and water supply systems.

Fifteen million dollars ($15,000,000) for planning and feasibility studies to identify potential options for the reoperation of the state's flood protection and water supply systems that will optimize the use of existing facilities and groundwater storage capacity.

(ii) The studies shall incorporate appropriate climate change scenarios and be designed to determine the potential to achieve the following objectives:

(I) Integration of flood protection and water supply systems to increase water supply reliability and flood protection, improve water quality, and provide for ecosystem protection and restoration.

(II) Reoperation of existing reservoirs, flood facilities, and other water facilities in conjunction with groundwater storage to improve water supply reliability, flood control, and ecosystem protection and to reduce groundwater overdraft.

(III) Promotion of more effective groundwater management and protection and greater integration of groundwater and surface water resource uses.

(IV) Improvement of existing water conveyance systems to increase water supply reliability, improve water quality, expand flood protection, and protect and restore ecosystems.

Appendix B. Key Words Used in UC Davis Library Literature Search

Key words:

- Fish passage
- Rim dam
- Fishway
- Dam
- Dams
- Dammed
- Hydroelectric
- Cost
- Econom*
- Fish bypass
- Fish ladder
- Fish transport
- Fish lock
- Fish elevator
- Fish lift
- Fish pass
- Trap and haul
- Fish migration
- Migration barriers
- Keystone dams
- Hydropower
- barrier